HOW BLACK HOLES SWALLOW STARS p. 24

DECEMBER 2021

Astronomy®

The world's best-selling astronomy magazine

SPECIAL REPORT

INSIDER'S GUIDE TO THE PLANETS

SOLAR SYSTEM MYSTERIES REVEALED p. 16

Antarctic total eclipse preview p. 44

+ Observing double stars p. 40
All you need to know about time p. 54
The history of Venus observations p. 48

www.Astronomy.com

BONUS ONLINE CONTENT CODE p. 4

Vol. 49 · Issue 12


Phantom
FCL 140-6.5 OTA
Super APO Imaging Refractor
by iStar Optical
$500
INSTANT SAVINGS!
istar-optical.com
Cutting Edge 2x ED & Dense Crown Optical Design
Outstanding Resolution & Zero Chromatic Aberration
Professional All metal CNC Machined Construction
Best Price-Quality Ratio in the Industry

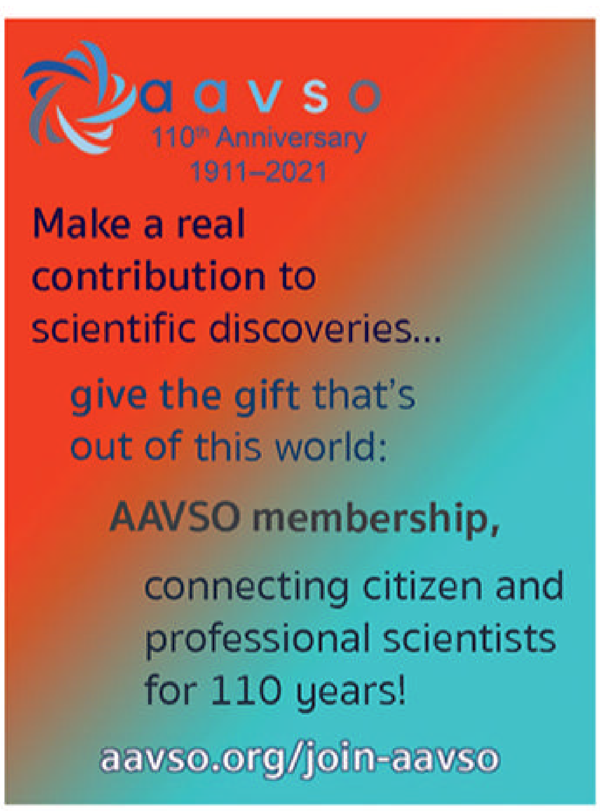

COLORFUL DEEP SKY OBJECTS IN MINUTES!
UNISTELLAR
UNISTELLAR
eVscope 2
Next Generation Smart Telescope


SPECIAL INTEREST
TOURS
Indonesia
Total Solar Eclipse
April 2023
SpecialInterestTours.com
Call 727-330-7738


OBERWERK
XL Series
XL = Excel
from Latin excellere to surpass, be eminent
1 to be superior to (an or others); surpass
2 to be outstandingly g or proficient
https://oberwerk.c


Great American Eclipse
Great American Eclipse.com
Your source for solar eclipse maps, viewers, books, globes, apparel, and more!
OCT. 14 2023
ANNULAR SOLAR ECLIPSE
APRIL 8 2024
TOTAL SOLAR ECLIPSE

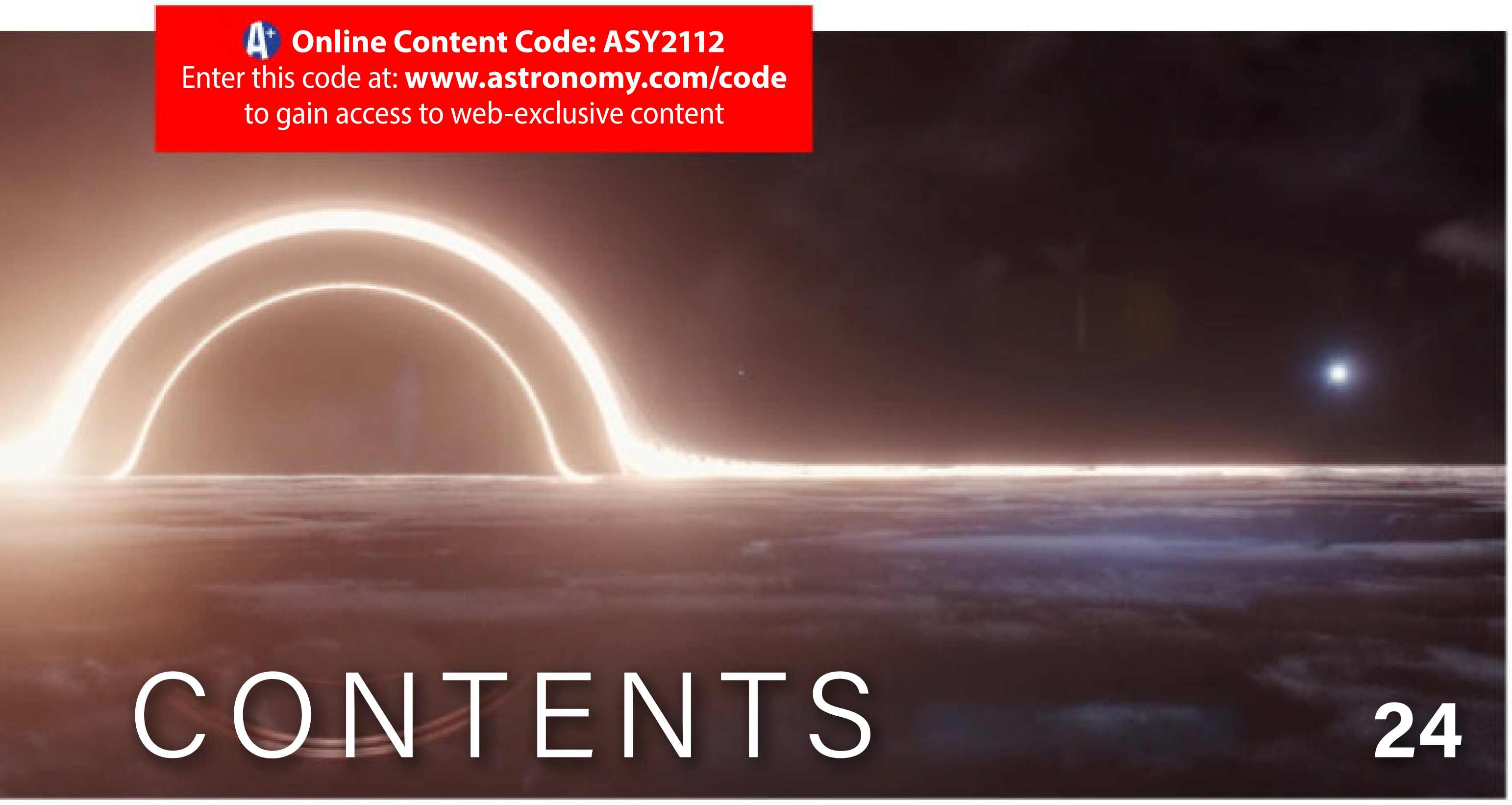

NIGHT SKY
STAR STENCIL
Ursa Major Stencils™ can brighten your wall or ceiling at night!
• 40 constellations
• Nearly 400 stars
• Smooth and textured ceilings
• Easy to apply, no stains
• Accurate depiction
• Kits start at $39.95
Astronomy READERS CHOICE 2019 WINNER
(844) 676-8772
www.UrsaMajorStencils.com


aavso
110th Anniversary
1911–2021
Make a real contribution to scientific discoveries...
give the gift that's out of this world:
AAVSO membership,
connecting citizen and professional scientists for 110 years!
aavso.org/join-aavso


10MICRON
astro•technology
MADE IN ITALY
Astronomical mounts
Advanced technology for your passion
330 lbs
GM4000 HPS II
www.10micron.eu/dealers


METEORITE & DIAMOND CUPOLA PENDANT
A FANCIFUL VIEW FROM THE ISS CUPOLA WINDOW IN 18K GOLD, METEORITE, AND A BLUE DIAMOND
STARTING AT
$2400.00
CAN BE CUSTOMIZED TO YOUR IMAGINATION
831.336.1020
METEORITEJEWELRYSTORE.COM

Online Content Code: ASY2112
Enter this code at: **www.astronomy.com/code**
to gain access to web-exclusive content



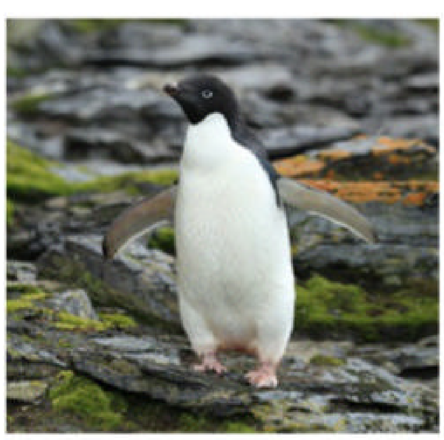
CONTENTS

24

DECEMBER 2021
VOL. 49, NO. 12

ON THE COVER
Saturn, our most beautiful planet, leads a parade of discoveries about the solar system. NASA/JPL

FEATURES



COLUMNS

IN EVERY ISSUE

ONLINE FAVORITES
Go to **www.Astronomy.com** for info on the biggest news and observing events, stunning photos, informative videos, and more.

My Science Shop
Perfect gifts for your favorite science geeks.

Trips and Tours
Travel the world with the staff of *Astronomy*.

Sky This Week
A daily digest of celestial events.

Ask Astro Archives
Answers to all your cosmic questions.

Astronomy (ISSN 0091-6358, USPS 531-350) is published monthly by Kalmbach Media Co., 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Periodicals postage paid at Waukesha, WI, and additional offices. POSTMASTER: Send address changes to *Astronomy*, PO Box 8520, Big Sandy, TX 75755. Canada Publication Mail Agreement #40010760.

Close look at the planets

Earth, our home planet, is a good base. But other planetary adventures await. NASA/JOSHUA STEVENS

Often we look deep into space for the latest findings beyond our home turf. But this is also a golden age of discovery and understanding of the solar system. In this issue, we pause to consider the magnificent vault of knowledge scientists have gained in recent times. Associate Editor Jake Parks summarizes this storehouse of research in his "Cosmic tour of the planets" (page 16).

Of course, life would never have existed on Earth without the Sun, our local nuclear reactor, located a mere 93 million miles away. The Sun formed in an open cluster about 4.6 billion years ago. What we know of the formation of our solar system — gravity pulling the material into a disk that rotates, helped along by angular momentum — tells us something about the worlds we are now discovering around other stars nearby in the galaxy.

The solar system's eight planets (or nine, for you Pluto fans!) encompass several basic types — gas giants, ice giants, rocky terrestrial worlds, and outer icy Kuiper belt objects. But we also know that the solar system didn't always look like it does now to us. Planets large and small likely migrated into their current positions. Numerous collisions accreted smaller bodies into bigger ones and caused important smashups, creating such bodies as our Moon and the moons of Pluto.

And although Earth lies in the temperate sweet spot for liquid water, and by extension for life, we also now know that microbes are far hardier and exist in more challenging extremes than anyone would have guessed a generation ago. Could the atmospheres of outer planets hold microbes? The subsurface aquifers on Mars? The icy, briny, subsurface oceans on outer solar system moons?

The possibilities are astonishing. Let Jake guide you on a whirlwind exploration.

Yours truly,

David J. Eicher
Editor

Follow the Dave's Universe blog: **www.Astronomy.com/davesuniverse**
Follow Dave Eicher on Twitter: **@deicherstar**

FOLLOW *ASTRONOMY*

facebook.com/AstronomyMagazine
twitter.com/AstronomyMag
youtube.com/user/AstronomyMagazine
instagram.com/astronomy.magazine

Astronomy

Editor David J. Eicher
Assistant Design Director Kelly Katlaps

EDITORIAL
Senior Editor Mark Zastrow
Production Editor Elisa R. Neckar
Senior Associate Editor Alison Klesman
Associate Editor Jake Parks
Associate Editor Caitlyn Buongiorno
Editorial Assistant Hailey McLaughlin

ART
Illustrator Roen Kelly
Production Specialist Jodi Jeranek

CONTRIBUTING EDITORS
Michael E. Bakich, Bob Berman, Adam Block, Glenn F. Chaple Jr., Martin George, Tony Hallas, Phil Harrington, Korey Haynes, Jeff Hester, Alister Ling, Stephen James O'Meara, Martin Ratcliffe, Raymond Shubinski, Richard Talcott

EDITORIAL ADVISORY BOARD
Buzz Aldrin, Marcia Bartusiak, Jim Bell, Timothy Ferris, Alex Filippenko, Adam Frank, John S. Gallagher III, Daniel W. E. Green, William K. Hartmann, Paul Hodge, Edward Kolb, Stephen P. Maran, Brian May, S. Alan Stern, James Trefil

Kalmbach Media
Chief Executive Officer Dan Hickey
Senior Vice President, Finance Christine Metcalf
Senior Vice President, Consumer Marketing Nicole McGuire
Vice President, Content Stephen C. George
Vice President, Operations Brian J. Schmidt
Vice President, Human Resources Sarah A. Horner
Advertising Sales Director Scott Redmond
Circulation Director Liz Runyon
Director of Digital Strategy Angela Cotey
Director of Design & Production Michael Soliday
Retention Manager Kathy Steele
Single Copy Specialist Kim Redmond

ADVERTISING DEPARTMENT
Advertising Representative Kristi Rummel
Phone (608) 435-6220
Email krummel@kalmbach.com

RETAIL TRADE ORDERS AND INQUIRIES
Selling *Astronomy* magazine or products in your store:
Phone (800) 558-1544
Outside U.S. and Canada (262) 796-8776, ext. 818
Fax (262) 798-6592
Email tss@kalmbach.com
Website www.Retailers.Kalmbach.com

CUSTOMER SALES AND SERVICE
Phone (877) 246-4835
Outside U.S. and Canada (903) 636-1125
Customer Service customerservice@AstronomyMagazine.info

CONTACT US
Ad Sales adsales@astronomy.com
Ask Astro askastro@astronomy.com
Books books@astronomy.com
Letters letters@astronomy.com
Products products@astronomy.com
Reader Gallery readergallery@astronomy.com
Editorial Phone (262) 796-8776

For reprints, licensing, and permissions:
PARS International at www.parsintl.com

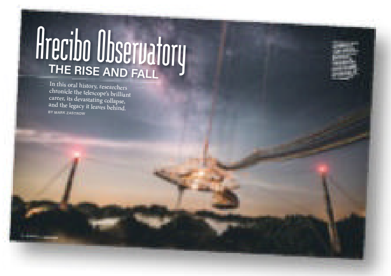
Crew members of Apollo 15 on the first lunar rover. NASA

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to **letters@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

A new light on Apollo

I've been enjoying your 50th anniversary article series on the Apollo lunar landings these last several years. Many of the historical details and photographs are new to me, and the two essays in the July issue on Apollo 15 did not disappoint. The photo of the crescent Earth rising above the Moon's limb, which I had never seen before, was mesmerizing. Thank you for sharing it with us! **—Justin Soutar,** Goshen, VA

Farewell, Arecibo



Your article in the August issue on the Arecibo Observatory was excellent! I usually like the hard science articles, but this one showed the very human side of doing astronomy in an observatory family. It was wonderful that the article was based upon the observations of the actual scientists there and not just written about Arecibo. In fact (though I am not a scientist), when I read the article, I found myself crying a bit along with Daniel Altschuler's account. A superlative and moving article! Keep up this excellent publication. **—Robert Walty,** Stephens City, VA

Predicting the future

Very nice coverage of NASA's current Perseverance and Ingenuity missions. As it happens, I recently watched the 2000 movie *Red Planet*. The mission included a rover with a helicopter. The rover was more like a robotic panther, but the helicopter was a dead ringer for Ingenuity. Was sci-fi predicting the future again?
—Jay Kaknes, Stowe, VT

Corrections

Our September story "The next 20 years of solar eclipses" listed the wrong information for the Dec. 4, 2021 eclipse. (The information provided was for the Dec. 14, 2020, total solar eclipse.) The Dec. 4, 2021, eclipse will be total only over Antarctica and the nearby ocean; see "A total solar eclipse over Antarctica" on page 44.

QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH

SNAPSHOT

MARTIAN STRING OF CRATERS

ESA captures a trio of impact craters.

Unlike Earth, the surface of Mars is rife with large, obvious impact craters. Estimates point to at least a quarter of a million such craters on the Red Planet. And with no plate tectonics, imperfections on Mars stick around for a lot longer than they do here on Earth.

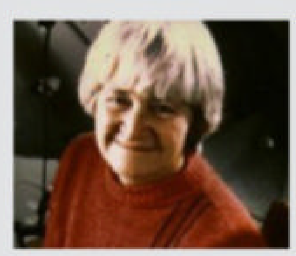
This orderly collection of craters sits in Mars' Lunae Planum, known for its rough terrain. Large lava deposits fill the region, likely spewed from the nearby Tharsis Montes volcanic region. The youngest volcanoes located there were last active as recently as a few million years ago. Some research even suggests the area may just be dormant for now and could erupt again in the future. The triplet of craters in this picture, taken by the Colour and Stereo Surface Imaging System camera on the European Space Agency and Roscosmos' ExoMars Trace Gas Orbiter, even bear evidence of the serial lava flows on their inner rims.

—CAITLYN BUONGIORNO

HOT BYTES

STANDING CLEAR

Research suggests that red dwarfs' most hazardous flares erupt mostly from their poles. This would mean the flares miss exoplanets that orbit in the stars' equatorial planes, improving those planets' prospects for hosting life.



HER WATCH HAS ENDED

The preeminent comet- and asteroid-hunter Carolyn Shoemaker died Aug. 13 at age 92. Among her finds was Comet D/1993 F2 (Shoemaker-Levy 9), which famously smashed into Jupiter in 1994.

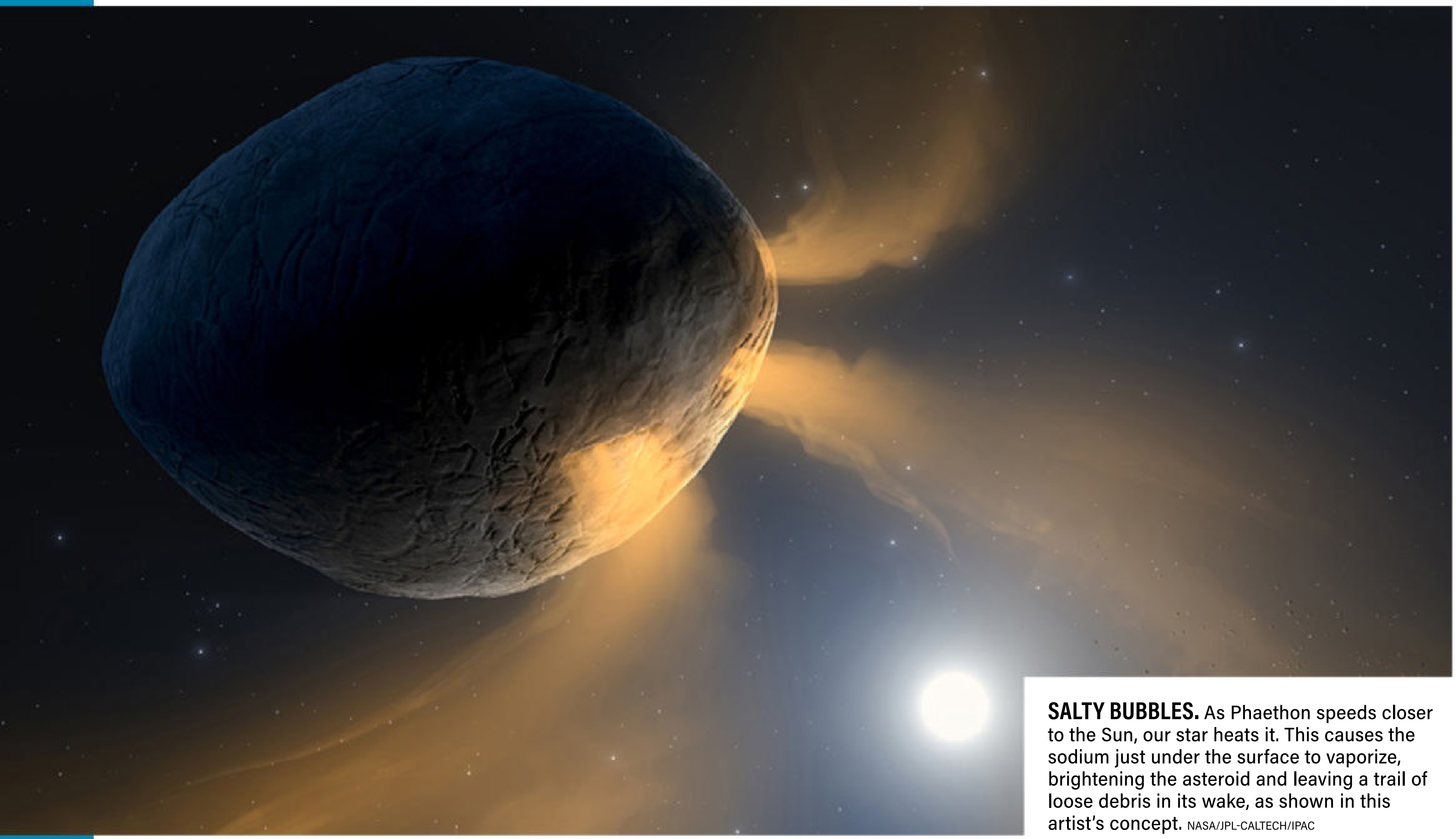
STUCK IN PLACE

An uncrewed demonstration flight of Boeing's Starliner spacecraft was postponed after some of the craft's propellant valves became stuck Aug. 3. The capsule was pulled from the launch pad Aug. 13 for further investigation.

CREDITS: ESA/ROSCOSMOS/CASSIS. BOTTOM FROM LEFT: AIP/ J. FOHLMEISTER; UNITED STATES GEOLOGICAL SURVEY; BOEING

SODIUM MAY MAKE ASTEROID PHAETHON FIZZLE

Bubbly sodium could explain this asteroid's cometlike behavior.



SALTY BUBBLES. As Phaethon speeds closer to the Sun, our star heats it. This causes the sodium just under the surface to vaporize, brightening the asteroid and leaving a trail of loose debris in its wake, as shown in this artist's concept. NASA/JPL-CALTECH/IPAC

» The Geminid meteor shower is best known for the reliable show it puts on during the winter holiday season. But the event is also unique because it stems not from a comet but from an asteroid: 3200 Phaethon.

Phaethon's true nature has puzzled astronomers for more than 10 years, ever since they discovered that it brightens dramatically and expels dust when it nears the Sun. That kind of behavior is usually reserved for comets. When a comet's path brings it through the inner solar system, the Sun warms and vaporizes the ices on its surface, creating a bright tail extending up to millions of miles behind it. Escaping vapor can also dislodge some of the comet's dust and rock, which is usually the debris that fuels meteor showers.

But asteroids like Phaethon are made of rock and metal, with little or no ice, leaving scientists to search for a different explanation for Phaethon's cometlike behavior. In a study published Aug. 16 in *The Planetary Science Journal*, researchers reported that they may have finally uncovered the culprit: sodium.

A FIZZY APPROACH

Aptly named after the son of the Sun god in Greek mythology, Phaethon has a 524-day orbit that brings it within just 0.14 astronomical units (AU; where 1 AU is the average distance between the Earth and Sun) of our star, well within Mercury's orbit. At that distance, the Sun heats the asteroid's surface to about 1,390 degrees Fahrenheit (750 degrees Celsius). Any water, carbon dioxide, or carbon monoxide ices just under the surface would have evaporated long ago, but sodium — an element abundant in asteroids — still could be fizzling just under its surface.

A steady bubbling of sodium would explain why Phaethon brightens as it approaches the Sun, as the resulting gas and dust would scatter more sunlight. It could also explain how the fuel for the Geminids breaks off from Phaethon.

"Asteroids like Phaethon have very weak gravity, so it doesn't take a lot of force to kick debris from the surface

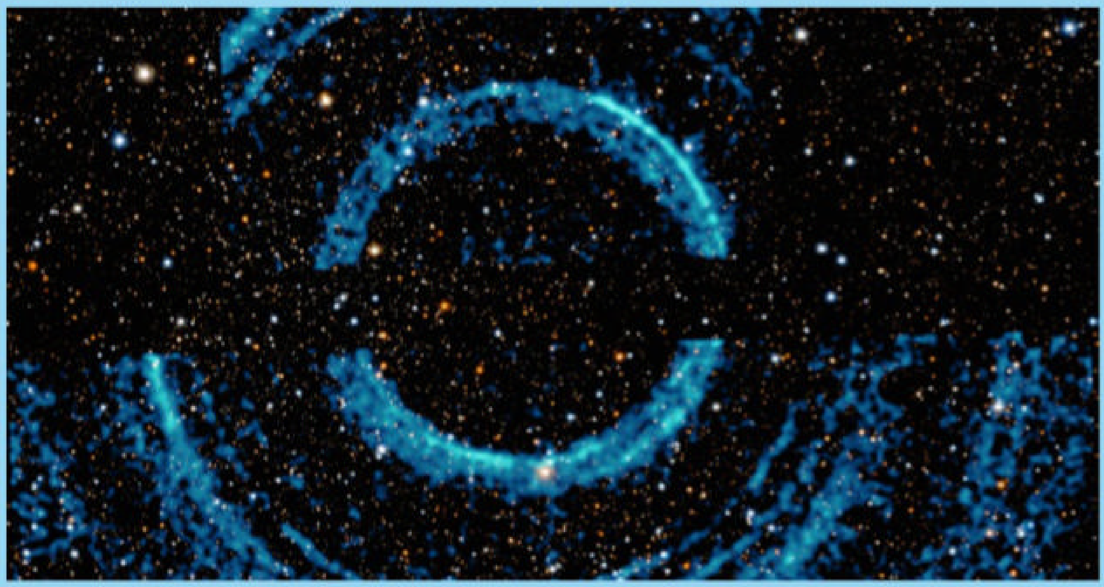
WINTER SPECTACULAR. Geminid meteors streak across the sky above Bill Evans Lake in New Mexico in this long-exposure photograph. Since first appearing in the mid-1800s, the Geminids have become one of the most productive meteor showers. This year, 150 meteors per hour are expected to be visible under very dark skies. STEPHEN DORN

or dislodge rock from a fracture," said study co-author Björn Davidsson of JPL in a press release. "Our models suggest that very small quantities of sodium are all that's needed to do this."

To determine whether sodium could indeed be the cause, the team heated chipped samples from the Allende meteorite — an object that fell to Earth in 1969 and may have originated from an asteroid like Phaethon — to the highest temperatures Phaethon experiences as it approaches the Sun. After subjecting them to heat for three hours — equivalent to a day on fast-spinning Phaethon — the researchers found that while other elements remained, the sodium in the chips had boiled away.

More data are needed to cement this as the reason for Phaethon's cometlike behavior, including repeating the test in a vacuum to better simulate Phaethon's environment. And although the researchers point out that this scenario depends a lot on the minerals present within a given object, they suspect that it could be applied to other active asteroids that have close approaches to the Sun. This study supports a growing body of evidence that classifying objects as either comets or asteroids may be too simple. As study lead author, Caltech's Joseph Masiero, put it, "The spectrum between asteroids and comets [is] even more complex than we previously realized." – C.B.

SEEING ECHOES OF LIGHT



X-RAY: NASA/CXC/UWISC-MADISON/S. HEINZ ET AL.; OPTICAL/IR: PAN-STARRS

A black hole recently gobbled up material from its companion star in the binary system V404 Cygni, located 7,800 light-years from Earth. As the black hole's meal swirled around it in 2015, the matter heated up and emitted a powerful burst of X-ray light. Like the sound waves of a yodeler echoing through the Swiss Alps, the light waves from the black hole's outburst are now echoing through the cosmos. This composite image, centered on V404 Cygni, spans some 80 light-years and reveals these so-called light echoes. Each concentric ring is formed as X-rays from the initial burst scatter off clouds of cosmic dust, redirecting the light toward us. The larger the ring, the closer the dust cloud that created it is to Earth. X-ray observations (blue) for this composite image were obtained by NASA's Chandra X-ray Observatory and Neils Gehrels Swift Observatory, while the background star field was imaged in optical and infrared light by the Pan-STARRS telescope in Hawaii. – JAKE PARKS

QUICK TAKES

NON-MAGNETIC MOON
The Moon likely never hosted a long-lived global magnetic field, according to new analysis of Apollo rock samples as old as 3.9 billion years. With no magnetosphere to ward off incoming charged particles, the lunar soil may have been enriched with resources deposited from space, such as Helium-3.

HIDDEN SUPERNOVA
An analysis of 40 dusty galaxies observed in infrared by the Spitzer Space Telescope revealed five supernovae previously undetected in visual observations. The study's lead author says the results suggest optical surveys miss up to half of all supernovae.

LAKE OR NO LAKE?
Many scientists thought Mars' Gale Crater, where NASA's Curiosity rover landed, hosted an ancient lake some 3 billion years ago. But a University of Hong Kong team says chemical patterns in the rocks Curiosity found suggest the crater's sediments were driven by winds or volcanic activity, not carried by water.

MAUNA KEA OF THE EAST
Chinese astronomers hope to build a world-class observing site near the summit of Saishiteng Mountain in the Tibetan Plateau. A three-year study showed the site features remarkably dry, stable air, as well as clear night skies about 70 percent of the time.

SATURN'S HAZY HEART
Saturn's core is a fuzzy region that contains about 17 Earth masses of sludgelike ice and rock, extending out to some 60 percent of the planet's radius. The find comes from a new analysis of the seismic waves, driven by pulsations within the planet itself, that Cassini observed in Saturn's rings.

SWEETENING THE POT
NASA awarded nearly $250,000 to a UC Berkeley team of chemists to help them refine their electrochemical process for making sugars from carbon dioxide. By feeding these sugars to microbes, the team hopes to produce more complex compounds, like food or drugs, for use by astronauts. – J.P.

Perseverance prevails, collects first sample

SECOND TIME'S THE CHARM. The borehole from Perseverance's first sample attempt (above) shows the target rock's poor integrity. On its second attempt at a different rock, the rover successfully drilled a sample and stored it in a titanium tube (left). FROM TOP: ASA/JPL-CALTECH/MSSS; NASA/JPL-CALTECH/ASU/MSSS

SOMETIMES, THE FAULT IS NOT IN OURSELVES, BUT IN OUR ROCKS. That's what happened to the Perseverance rover during its first attempted sample collection in Jezero Crater.

NASA's newest rover is on a mission to not only explore Mars but also collect samples that can be studied on Earth. Perseverance is carrying numerous tubes to store small, drilled core samples of rock for a later mission to retrieve.

But on Aug. 6, NASA announced that the rover's first collection attempt had turned up empty. The rover had successfully gone through the motions — drilling into the rock and attempting to place the result into a tube. But when the rover stuck a probe inside the tube to measure the volume of the sample, it found nothing.

Mission controllers were confident the rover's drill and coring bit were in good working order. So, they concluded, it was the rock that had misbehaved. Called Roubion, this first target is what researchers refer to as a paver stone — flat, polygonal rocks they believe are some of the most ancient in the area. But because such rocks are old and weathered, this one crumbled under the force of Perseverance's drill.

To find a better target, controllers next drove to a ridge called Citadelle, with outcroppings of rocks very different from the paver stones. And, on Sept. 2, Perseverance successfully completed its first sample collection. This time, images from the rover showed the rock core, a bit wider than a pencil, snug in its sample tube.

The team still hopes to sample a paver stone. Next time, though, they'll likely target a less weathered type of paver, in the hopes that such rocks will provide information similar to older, more fragile examples. —ALISON KLESMAN

The Milky Way has a broken arm

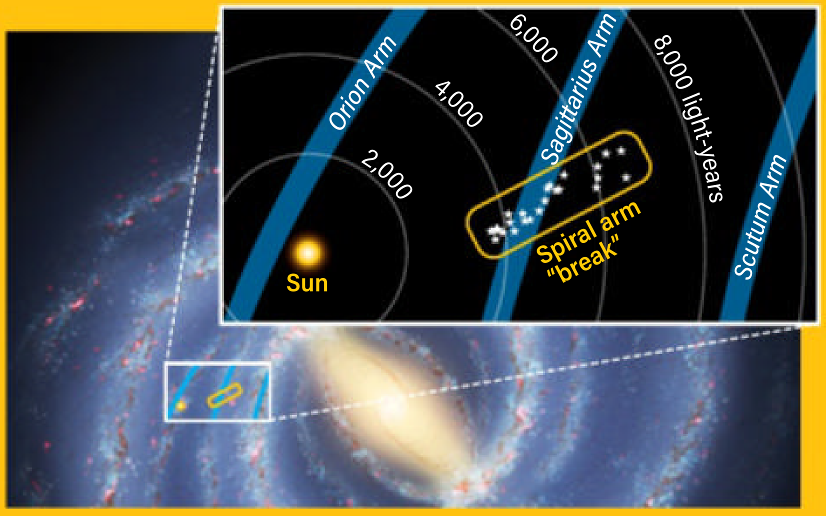
Even though we call it home, the Milky Way remains rich with mysteries and surprises. Case in point: Astronomers recently noticed our galaxy has a broken arm.

Stretching about 3,000 light-years long, this splinter of stars and gas juts out from the Sagittarius Arm at a roughly 45° angle. While it's not unusual to spot sharply-angled spurs (also called feathers) in other spiral galaxies, it's the first time that astronomers have noticed a defect this stark in our own galaxy's arms.

From Earth's position within the Milky Way, it's difficult for scientists to see the entirety of the galaxy. Astronomers used data obtained by the now-retired NASA Spitzer Space Telescope and by the European Space Agency's Gaia mapping mission to confirm they were seeing a section of the Milky Way protruding from the rest of the arm. "It is only the recent, direct distance measurements from Gaia that make the geometry of this new structure so apparent," said study co-author Alberto Krone-Martins, an astrophysicist at the University of California, Irvine, in a statement.

Though this would be a rather gruesome fracture in flesh and bone, in cosmic terms, this area is spectacular, filled with star-forming vistas. The analysis shows that four famous deep-sky objects — the Eagle Nebula (M16), the Omega Nebula (M17), the Trifid Nebula (M20), and the Lagoon Nebula (M8) — all lie within this structure.

Astronomers believe such spurs are formed by a combination of gravity, rotation, and shear. Because these structures bear the imprint of those forces, finding more spurs like this one could help scientists better understand how spiral galaxies form their graceful, curving arms. —HAILEY ROSE MCLAUGHLIN



NO CAST REQUIRED. A collection of stars and gas clouds jut awkwardly from the Milky Way's Sagittarius Arm in this artist's concept. The distance and size of the break is shown in the inset. NASA/JPL-CALTECH

JUPITER'S AURORAE TRIGGER HEAT WAVES

FOR 50 YEARS, researchers have struggled to explain one of Jupiter's enduring mysteries: Why is its upper atmosphere so hot? Based on the intensity of sunlight Jupiter receives, its highest reaches should be a brisk –100 degrees Fahrenheit (–73 degrees Celsius). Instead, they sizzle at about 800 F (426 C).

One hypothesis held that Jupiter somehow generates heat from below — perhaps from storms lower in its atmosphere. Or, some speculated, its innards could still be gravitationally settling and releasing heat.

But the main suspect has been Jupiter's aurorae, which are produced when the planet's powerful magnetic field traps charged particles and funnels them to its poles. When those particles smash into atmospheric molecules, they cause them to glow — and inject a tremendous amount of energy into the atmosphere above the poles in the process.

While, in principle, this could heat the entire planet, atmospheric models have predicted that the planet's strong winds trap heat at the poles and prevent it from spreading to lower latitudes.

But a study published Aug. 4 in *Nature* suggests those models may be missing something. An international team of researchers used the Keck Observatory in Hawaii to measure infrared emission from hydrogen molecules in Jupiter's atmosphere, producing a high-resolution temperature map of the planet.

Their analysis revealed that the polar regions directly under the aurorae were some 720 F (400 C) hotter than equatorial climes, clear evidence of the aurorae's ability to heat the poles. And on the team's second night of observations (Jan. 25, 2017, roughly nine months after their first), they also found evidence that this heat can spread elsewhere: A hot band appeared south of the main auroral oval, 360 F (200 C) warmer than its surroundings and wrapping halfway around the planet. The team argues this is a wave of heat traveling from the poles toward the equator.

Strengthening their case, they note that the wave occurred at a time when the solar wind was predicted to be relatively strong at Jupiter, which would have likely triggered more intense auroral heating.

"It was pure luck that we captured this potential heat-shedding event," said James O'Donoghue, a planetary scientist at the JAXA Institute of Space and Astronautical Science in Sagamihara, Japan, and the study's lead author, in a press release. "If we'd observed Jupiter on a different night, when the solar wind pressure had not recently been high, we would have missed it!"

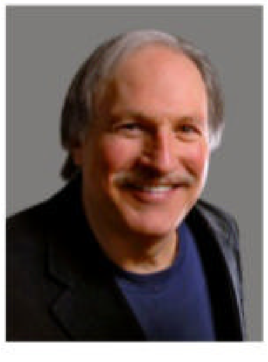
The team thinks this event shows the aurorae are likely responsible for most of Jupiter's excess heat — though exactly how Jupiter's atmosphere manages to circulate that heat remains unclear. —MARK ZASTROW

GLOBAL WARMING. Waves of heat emanate from Jupiter's aurorae, distributing energy from the poles toward the planet's equator, in this illustration of an infrared view.
J. O'DONOGHUE (JAXA)/HUBBLE/NASA/ESA/A. SIMON/J. SCHMIDT

Chances are …

Let's dive deeper into randomness.

The chances that the Orion Nebula (M42) looks exactly as it does are 100 percent — if you're calculating them today, after it has already formed. NASA, ESA, M. ROBBERTO (SPACE TELESCOPE SCIENCE INSTITUTE/ESA) AND THE HUBBLE SPACE TELESCOPE ORION TREASURY PROJECT TEAM



BY BOB BERMAN
Bob's recent book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

Nearly nine years ago, this page explored randomness and its apparent ability to generate the universe around us (see my January 2013 column, "It's random"). Since then, science articles have continued to cite chance — such as a planet happening to sit a specific distance from its parent star — as the presumed mechanism for life on exoplanets.

It's tempting to attribute natural phenomena to chance because we already see it operating widely. For example, it's how evolution works. The problem is that few people seem to understand the limits of chance. I think it's time to give this subject a deeper look.

Let's expand on some of my previous examples: Consider putting eight books on a shelf. How likely is it that their titles will appear in alphabetical order? You'll find the odds by multiplying 8 x 7 x 6 x 5 x 4 x 3 x 2 x 1 — pronounced "eight factorial" and written as 8! — which equals 40,320. That's how many ways eight books can be arranged. But only one of those ways puts them in alphabetical order. This will surprise most of us. Who would expect such long odds? After hastily putting up eight volumes and noticing they're perfectly alphabetical, it might seem more plausible that we'd witnessed a 1-in-50 curiosity than a 1-in-40,000 miracle.

It's tempting to attribute natural phenomena to chance.

More important than such statistical surprises is whether we apply randomness correctly. Scientists occasionally argue an event should be studied because it's so unusual by committing the statistical felony of calculating its likelihood *after* it has happened. We might say the Orion Nebula's gull-wing pattern is a 1-in-a-million phenomenon. But those odds are valid only if we calculated them before the nebula's creation. Once M42 exists, its chances of looking as it does become 100 percent! It's no longer unlikely in the least.

Perhaps the most famous statistical illustration of randomness is the monkeys-and-typewriters thought experiment. If a million monkeys typed randomly on a million keyboards for a million years, they'd supposedly create the *Encyclopaedia Britannica*. True?

We figured it out on this page nearly a decade ago. But we limited the task to creating the opening line of *Moby Dick*: "Call me Ishmael." Now, keyboards offer many places to push — manual typewriters have 58 keys. So, to create *Moby Dick*'s 16 opening characters (including spaces and punctuation), how many random tries are needed?

Given 58 keys, it would be 58 x 58 x 58 x 58… 16 times over, or 16.4 trillion quadrillion attempts. But remember we have a million monkeys working; let's say they faultlessly type 45 words a minute so the combined keystrokes in each attempt take just four seconds. How much time before there's a 50-50 chance that one monkey finally types "Call me Ishmael"? The answer is 2,100 trillion years. That's 153,000 times the age of the universe.

So, the monkeys/typewriters thing is bogus. Even a million simians typing furiously would never even reproduce one book's short opening line.

My cautionary point nine years ago and again today is to avoid overly crediting the power of random causation, whether through monkeys or molecular motion. We may observe complex earthly phenomena such as brain architecture, marvel at the exquisitely life-friendly values of dozens of physical constants such as the strong force, or even someday find alien life and ponder how it arose. But we shouldn't lazily assume their explanation is randomness operating over a long period of time. In most cases, this supposition is simply not useful. It seldom advances our knowledge because, as we've seen, we assign it far more potency than it actually possesses.

Chance is a valid causality method, and a powerful one. But we need to recognize its inadequacy when excessive complexity is involved and more fundamentally guard against applying it after the fact.

Where does this leave us? At some point in our lives, we've all wondered about the causality of big issues. Astronomy is peerless at provoking such torment. If chance is grossly overused but we also want to avoid religious explanations, what's left?

Count me among the many who, when contemplating this astounding universe, perceive Nature as exhibiting some sort of underlying intelligence. We seem immersed within a mysterious, genius architectural substrate so deep we haven't yet begun to poke it with our clumsy fingers. Alas, even if true, this hypothesis may be no more helpful to scientific progress than simply leaving everything … to chance.

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman**

Psychology of stargazing

What motivates backyard astronomers?

Star trails circle Polaris above the Liberty Schoolhouse, an old, single-room building on the Alberta prairie. It's illuminated by an eight-day-old waxing Moon in this long exposure, and aurorae are also visible dancing above the northern horizon. ALAN DYER

BY GLENN CHAPLE

Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

This month, we're going to step away from our usual observing content and instead take a look at the psychology of skygazing. In short, we'll ruminate on what makes us backyard astronomers tick. Why do we prefer reading *Astronomy* to, say, *Field & Stream*, *Better Homes and Gardens*, or *Popular Mechanics*? What compels us go outside on a clear starlit evening and gaze heavenward while our neighbors are indoors watching TV or playing games?

I used to think a proclivity for backyard astronomy had to do with a love of the outdoors. That might be because my three favorite activities are stargazing, fishing, and recreational running. All involve being out in open air, away from the confines of home or workplace. But nowadays, there's a growing cadre of indoor astronomers who explore the night sky via a computer linked to a remotely placed telescope. To me, that proves that a passion for amateur astronomy has to do with more than just satiating an urge to be outdoors.

Perhaps personality type plays a role? Years ago, I took a Myers-Briggs personality test at the middle school where I taught. I won't get into a discussion of the veracity of Myers-Briggs (it's discredited by a majority of clinical psychologists), and I don't recall my ultimate four-letter personality type, but I do remember that I was categorized as an introvert. At the time, I imagined an introvert to be a stereotypical wallflower — quiet, shy, and withdrawn. Yet I was that 7th-grade science teacher who once did an Elvis Presley impersonation at the middle school talent show. Still, I have to admit that when I wasn't singing "All Shook Up" in front of 500 preteens, running a marathon with hundreds of others, or competing in a bass-fishing tournament, I really preferred my alone time. An evening under the stars with just my telescope was a soul-refreshing occasion — although the same could be said for reading a good book or binging the latest Netflix show.

Curiosity! That has to be a personality trait that all amateur astronomers share. I've always maintained that the best scientists are 4-year-olds who wonder why the sky is blue, what clouds are made of, and what causes the wind. Amateur astronomers (dare I say all astronomers, professionals included) never lost that childhood curiosity. As adults, we now ask more advanced questions: What causes the ruddy appearance of Jupiter's Red Spot? What is the composition of a typical emission nebula? What is the driving force behind the solar wind? But even these questions stem from the same curiosity that kids have to understand the world around them.

Patience is also a virtue, especially for the backyard astronomer. It took plenty of patience for humanity to become familiar with the basic stars and constellations, and we're still learning how to best build and utilize telescopes to explore the wonders the night sky has to offer. The inspiring images that appear at the back of this magazine were taken by amateur astronomers who dedicated many hours to learning and perfecting their craft. And an impatient person would never be able to handle a telescope-making project.

Patience is also a virtue, especially for the backyard astronomer.

Let's get back now to the psychology of skygazing. Perhaps backyard astronomers are largely outdoor-loving, introverted, curiosity-driven, and patient. But why are some of us primarily visual observers, while others engage in astroimaging? Why do some feel the urge to devote an entire evening to a Messier or Double Star Marathon while others are content spending a relaxed hour or two hopping between a handful of celestial targets? Why do some focus on deep-sky objects while others prefer to observe the Moon and planets? I could go on and on, but this is *Astronomy* and not *Psychology Today*.

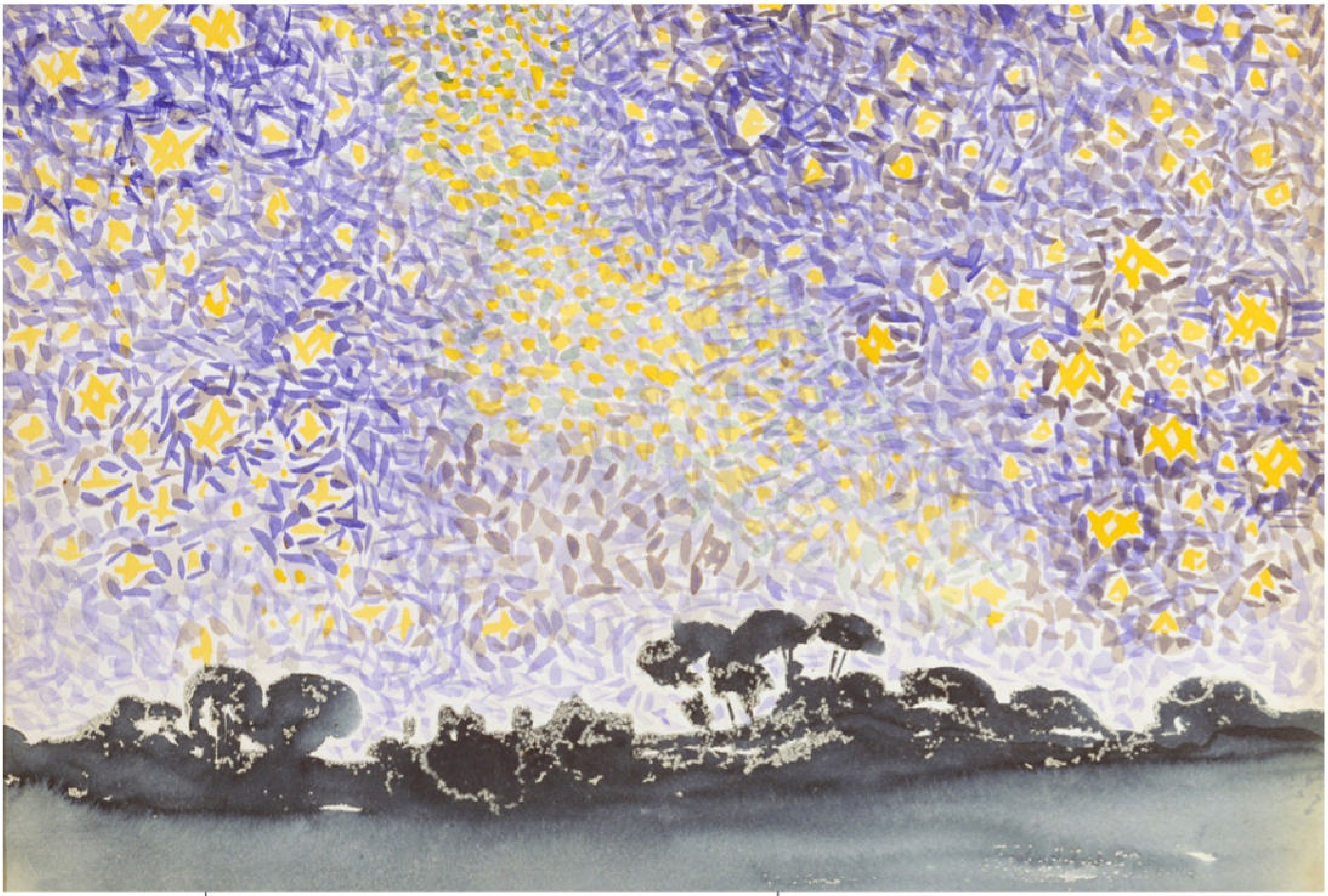
Perhaps we should just leave the psychoanalysis to the psychologists. Whether we use a laptop to remotely image a distant galaxy, go to a workshop to grind a mirror for a telescope, venture outside to target double stars, or simply lie back in a hammock and contemplate the enormity of the universe, we're all the same. We share a common passion for one of the oldest and noblest of human activities — astronomy!

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: I'll take a quick break before kicking off my farewell tour. Clear skies!

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple**

'Violettomania' in the stars

The simultaneous rise of the color violet in both astronomical observations and art is no coincidence.



French artist Henri-Edmond Cross' *Landscape With Stars* (circa 1905–1908) is a poetic depiction of a star-streaked sky, reminiscent in its impressionistic forms of a Japanese painting. ROBERT LEHMAN COLLECTION, 1975/THE METROPOLITAN MUSEUM OF ART

BY STEPHEN JAMES O'MEARA
Stephen is a globe-trotting observer who is always looking for the next great celestial event.

British astronomer Admiral William Henry Smyth may have been a pioneer in applying color science to astronomy. His 1844 *Cycle of Celestial Objects* is filled with colorful descriptions of double and multiple stars — including smalt blue, flushed white, orpiment yellow, dusky orange, and cherry red. While most of the star colors he perceived (sans adjectives) were among those considered most distinct to visual astronomers (blue, yellow, orange, and red), Smyth also saw among the stars his share of violet — a color beyond the blue end of the spectrum. But the reason he saw them may be more than just simple physics.

Violet is a color hard to find not only in nature but also, historically, in art. That's the conclusion reached by Russian American artist and cognitive scientist Allen Tager, who, over the course of 20 years, visited 193 museums in 42 countries and examined nearly 140,000 works of art to see how many incorporated the color violet. As he wrote in a June 23 article for *Psyche*, Tager found very few paintings using violet before the 1860s, when the French Impressionists adopted the color in earnest.

To investigate further, Tager teamed up with color scientists Eric Kirchner of the paints company AkzoNobel and Elena Fedorovskaya at the Rochester Institute of Technology. They used computer algorithms to analyze more than 4,000 digitized works of art. In a paper published March 13 in the journal *Color Research & Application*, they reported that prior to the mid-19th century, violet appeared in fewer than 4 percent of paintings. But this rate quickly rose to 37 percent

in the second half of the 19th century and spiked to 48 percent in the 20th century.

The researchers also discovered discrepancies over what constitutes the color violet. For instance, the color beyond blue on the spectrum is called purple in the U.S., but violet in the U.K.; alternatively, reddish-purple is sometimes called violet in the U.S., but hardly ever so in the U.K. This led Tager and his colleagues to create the first working definition for the color violet: "all mixtures of red and blue for which blue dominates."

LEFT: William Henry Smyth presented this color scheme for double stars in his *Sidereal Chromatics*. "Where the mental impression is not quite adequately represented by these tints," he said, "it can be modified by an expressive adjective." The shades from white to pale yellow were so numerous, he excluded them from the chart. Violet and lilac would be registered under "purple." COURTESY OF STEPHEN JAMES O'MEARA

Introducing violet

In his 1864 book *Sidereal Chromatics (On the Colours of Multiple Stars)*, Smyth recognizes an evolution not just in art but also in the color perception of skywatchers. "The ancients recognised no blue stars," he says. "They only spoke of white or red ones." Blue stars, he notes, were not introduced into the astronomical lexicon until French physicist Edme Mariotte first mentioned them in 1686. Smyth also notes that "although single red stars are frequently met with, there is not an instance of a solitary green, purple, blue, or violet-coloured one being found."

However, Smyth did note the appearance of violet in double stars. In fact, he appears to be the first telescopic observer to use the color violet in his descriptions of stars. For instance, as early as the 1830s, he recorded numerous double stars with white or yellow primaries and a violet secondary. To my knowledge, all observers before him stuck to the traditional color schemes in their descriptions of double stars. Observers following Smyth, however, began incorporating violet into their double star vocabulary, albeit sparingly.

Smyth appears to be the first telescopic observer to use the color violet in his descriptions of stars.

Inspired by science

In their March 2021 paper, Tager and his colleagues describe how contemporary developments in color theory and their adoption by Impressionist painters may naturally have led to an increase in the use of violet from 1863 onwards.

Interestingly, in the early years of the Impressionist movement, we see Smyth promoting in his *Sidereal Chromatics* "the laws of harmonious alliance and contrast of colour — that yellow is of all hues the nearest related to light, and its complementary violet or purple to darkness." The above quote seems to indicate that Smyth was familiar with Goethe's analysis of the sensory and psychological effects induced by different colors, which he published in his 1810 work *Theory of Colors*.

Smyth then goes on to say, "Many of the observed tints of stellar companions would of course turn out to be merely complementary [colors] and caused by the law of simultaneous contrast." This concept, introduced by French chemist Michel Eugène Chevreul (and inspired by Goethe) in his 1839 *The Principles of Harmony and Contrast of Colours*, blossomed around the time that Smyth was making his color observations, some 25 years before he published *Sidereal Chromatics*.

Chevreul's law stated that when two adjacent colors are observed, their perceived colors shift toward the complementary color of the adjacent color. For a binary star that contains a bright, slightly orange-yellow star next to a white star, Chevreul's law predicts that the human eye will see the color of that white star shifted toward violet. That's because violet is the complementary color to yellow, as they are opposing hues on a color wheel. These inferences suggest that science theory had begun to make its mark on visual telescopic observations by the mid-19th century.

BELOW: The double star Albireo's primary has a spectral type of K2, emitting an yellowish-orange glow; the secondary is B8 — nearly pure white. But due to complementary colors, the secondary often takes on a brilliant blue hue. KFIR SIMON

And it was this type of optical effect (simultaneous contrast for colors) that the Impressionists sought to capture and exploit in their works. This allowed them to create even stronger color contrasts — a canvas bristling with scientific proof that what the eye perceived and the brain understood were two different things. "Impressionist painters used the colour violet so prolifically," Tager wrote for *Psyche*, "that critics accused them of violettomania."

While the range of colors of stars are limited to hues that vary from reddish orange to pale blue, what our eye-brain system sees depends on many factors. These include atmospheric clarity, the telescope used, contrast, and bias (from knowledge of a star's spectral class and color temperature), among others. But don't let that stop you from recording what you see rather than what you are expected to see.

And as always, report what you see or don't see to sjomeara31@gmail.com.

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara**

Cosmic tour of the

EARTH

Our planet, despite all the challenges we face living on it, is an unparalleled abode for life. Located in the Sun's so-called Goldilocks zone, the energy we receive from our host star is just right. It keeps Earth warm enough that liquid water can happily exist on the surface, but it's also weak enough that our oceans don't boil away. Then there's our atmosphere — what a blessing! This thick (but not oppressive) gaseous envelope not only provides us with the oxygen we need to breathe, but also protects us from all but the most formidable stray space rocks. And let's not forget our planet's magnetic field. Generated deep within Earth's liquid outer core, which surrounds a solid inner core, this magnetic shield defends us from the constant onslaught of high-energy particles spewed out by the Sun as solar wind.

But impressive as Earth is, life has existed here for billions of years. And we already know quite a lot about our home world (even if there's still plenty left to discover). So, instead of looking inward, let's look out. Let's take a quick tour of the other planets our solar system has to offer. Along the way, we'll brush up on what we already know — as well as what we may soon find out.

BOTTOM LEFT: Multiple large hurricanes are seen brewing in the Atlantic Ocean in this composite assembled from images taken by a NASA/NOAA weather satellite on Sept. 6, 2017. NASA/JOSHUA STEVENS

BOTTOM RIGHT: The Expedition 7 crew aboard the International Space Station captured this stunning view of the Sun setting over the Pacific Ocean in 2003. NASA

STATS

Mass: 10.3 septillion pounds (5.97×10^{24} kilograms)
Diameter (equator): 7,930 miles (12,760 kilometers)
Average surface temperature: 59 degrees Fahrenheit (15 degrees Celsius)
Rotation period (day): 23 hours 56 minutes 4 seconds
Orbital period (year): 365.26 days
Moons: The Moon

planets

With thousands of exotic exoplanets known, the worlds of our solar system may seem rather dull. Trust us, they're not.

BY JAKE PARKS

The heavily cratered surface of Mercury's southern hemisphere is on full display in this mosaic of images taken by NASA's Mariner 10 spacecraft, which was the first mission to fly by and closely scrutinize our solar system's innermost world. NASA/JPL-CALTECH

MERCURY

Mercury, which is the smallest and innermost planet, is constantly cooked by sunlight. Despite its proximity to our star, it's not the hottest world in our solar system; still, Mercury experiences wild temperature swings unlike those found on any other planet. On the dayside, the Sun penetrates the planet's thin, fleeting atmosphere and bakes the surface. But because there isn't much air to distribute that heat, the temperature on the planet's nightside plunges to hundreds of degrees below zero.

The Sun also helps give Mercury another peculiar trait: The world has a faint cometlike tail. Mercury's feeble atmosphere contains sodium, which glows when excited by sunlight. Plus, the diminutive world doesn't have much gravity — only about twice the gravity of the Moon. This means pressure from sunlight striking Mercury can liberate sodium molecules, forcing them "downwind" of the planet and creating a dimly glowing tail.

Thanks to its thin atmosphere, Mercury is also prone to impacts. This has left it with a rather pockmarked appearance. And to make matters worse, it's wrinkled with age. The world has steep, clifflike north-south ridges that stretch all over its surface. Researchers think they might have formed as Mercury cooled after its birth, causing the planet to shrink and its crust to slightly crumple.

Mercury has so far been visited by only two spacecraft: Mariner 10 (launched in 1973) and MESSENGER (launched in 2004). The former was a flyby mission that only revealed a partial view of the tiny planet. However, the latter was an orbiter, which not only mapped the vast majority of Mercury's surface, but also discovered that the planet's permanently shadowed polar craters likely hold abundant water ice.

If you'd like to learn more about what Mercury has to offer, you need not wait long. The European and Japanese space agencies have teamed up and sent BepiColumbo to orbit Earth's smallest sibling — and Bepi just made its first brief pass by the oft-forgotten planet this October. Stay tuned for more!

STATS

Mass: 0.055 Earth masses
Diameter: 3,030 miles (4,876 km)
Surface temperature: 805 F (430 C) during the day -290 F (-180 C) at night
Rotation period (day): 58.8 Earth days
Orbital period (year): 88 Earth days
Moons: None

Mercury's surface is covered in wrinklelike ridges. This unnamed example of such a ridge is located in the planet's northern volcanic plains and was imaged by NASA's MESSENGER spacecraft. The feature spans some 87 miles (140 km) and, like the world's other wrinkles, is believed to have formed when Mercury's core shrank as it cooled, which forced the surface to follow suit. NASA/JHUAPL/CARNEGIE INSTITUTION OF WASHINGTON

VENUS

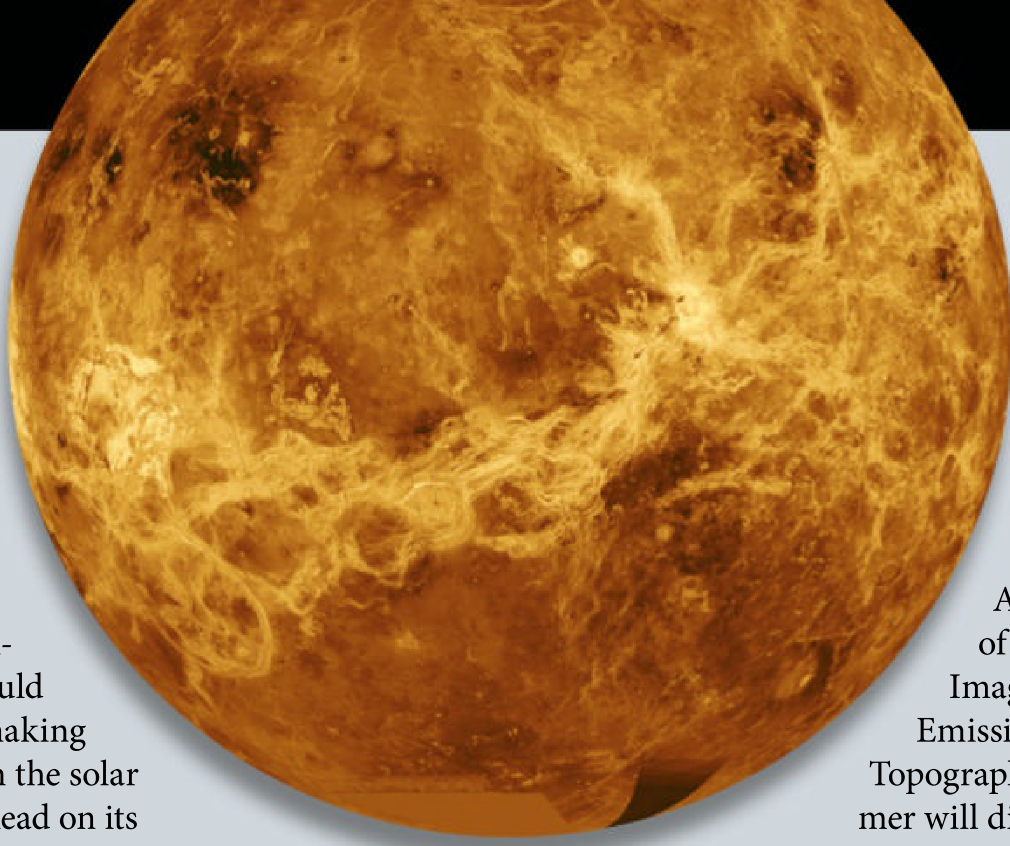
Despite being the most brilliant planet in our sky, Venus offers little visual oomph when observed from afar. (See "Unveiling Venus" on page 48.) That's because its surface is shrouded by thick, omnipresent clouds. These poisonous puffs trap heat that would otherwise escape into space, making it the most sweltering planet in the solar system — hot enough to melt lead on its surface. But don't worry about burning up: If you were to stand there, the atmosphere (made mostly of carbon dioxide laced with sulfuric acid) is so dense that the pressure would collapse your lungs and kill you instantly.

Despite its hellish environment, Venus holds many fascinating mysteries. For one, it's strikingly similar to Earth in size and composition. And yet, the worlds have clearly led two very different lives, with Venus experiencing a runaway greenhouse effect in its past. Unlike Mercury, whose bulky iron core accounts for some 75 percent of the planet's mass, the core of Venus is thought to be relatively earthlike: differentiated into a solid inner core and a molten outer core. However, Venus does not internally generate a discernible magnetic field like Earth does, which might be because it rotates (backward) so slowly that a venusian day is longer than a venusian year.

Steadily, though, Venus is revealing some of its secrets. The veil created by its clouds was finally lifted in 1994, when the Magellan spacecraft completed a five-year mission that, among other things, used cloud-penetrating radar to map some 98 percent of the world's cloaked surface. As incredible as Magellan's work was, however, a trio of new spacecraft recently selected to explore Venus in the next decade are sure to raise the bar even higher.

On June 2, NASA announced not one, but two complementary missions to Venus: DAVINCI (short for Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging) and VERITAS (Venus Emissivity, Radio Science, InSAR, Topography & Spectroscopy). The former will dive through Venus' atmosphere, snapping pics of the environment and sampling the world's acidic clouds before slamming into its surface. That bold plan will allow scientists to stitch together a layer-by-layer profile of Venus' atmosphere — and perhaps even confirm the floating phosphine detected there last year, which tantalized many because it is often produced by microbial life on Earth. Meanwhile, VERITAS will orbit Venus, using radar and imaging equipment to investigate whether the world is actively experiencing volcanic activity and, if so, learn what might be driving it.

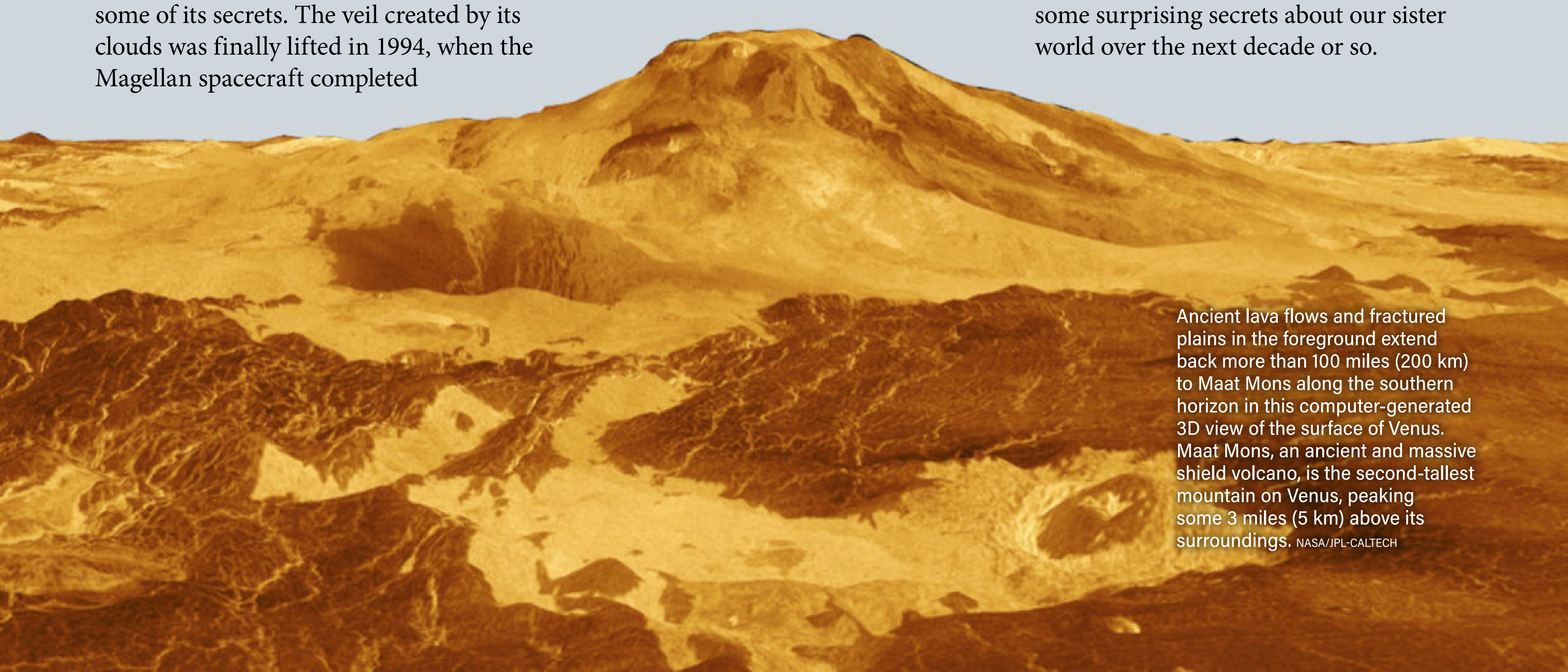
And don't forget EnVision, the European Space Agency's contribution. This orbiting craft will use a sounder to study Venus' underground layering, radar to map its surface, spectrometers to analyze trace atmospheric gases, and a radio experiment to probe the planet's internal structure and gravitational field. With such an impressive trio preparing to venture to Venus, it's safe to say we'll unlock some surprising secrets about our sister world over the next decade or so.



Venus' surface, usually shrouded by the planet's dense atmosphere, bursts into view in this simulated-color radar mosaic assembled using data from the Magellan spacecraft's first mapping campaign. Data from the Pioneer Venus Orbiter were used to fill in the gaps. NASA/JPL-CALTECH

STATS

Mass: 0.815 Earth masses
Diameter: 7,520 miles (12,100 km)
Surface temperature: 867 F (464 C)
Rotation period (day): 243 Earth days (retrograde)
Orbital period (year): 225 Earth days
Moons: None



Ancient lava flows and fractured plains in the foreground extend back more than 100 miles (200 km) to Maat Mons along the southern horizon in this computer-generated 3D view of the surface of Venus. Maat Mons, an ancient and massive shield volcano, is the second-tallest mountain on Venus, peaking some 3 miles (5 km) above its surroundings. NASA/JPL-CALTECH

MARS

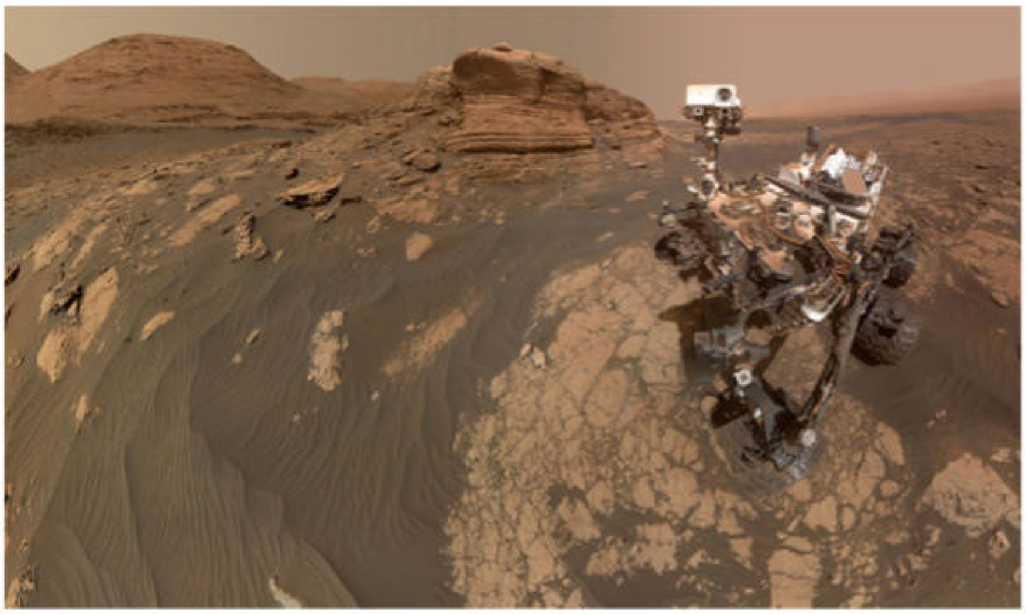
As the most explored world in the solar system (save Earth), Mars has enjoyed the lion's share of planetary research funding for several decades. We've come a long way since Italian astronomer Giovanni Schiaparelli first mapped his martian *canali* ("channels," which was mistranslated to "canals") in 1877. Nearly a century later, in 1965, NASA accomplished the first up-close and personal flyby of Mars with Mariner 4. In the decades since, dozens more spacecraft have incrementally advanced our understanding of the Red Planet.

Orbiters have thoroughly mapped Mars' surface. Landers have probed the planet's internal structure and monitored the local weather. Rovers have trundled across the desertscape to collect and analyze rock samples. And one small NASA helicopter named Ingenuity recently zipped through the martian atmosphere more than a dozen times — no small feat considering Mars' air is just 1 percent as dense as Earth's. This opens the door to future fleets of flying scouts that could explore broad swaths of the planet at an incredible pace.

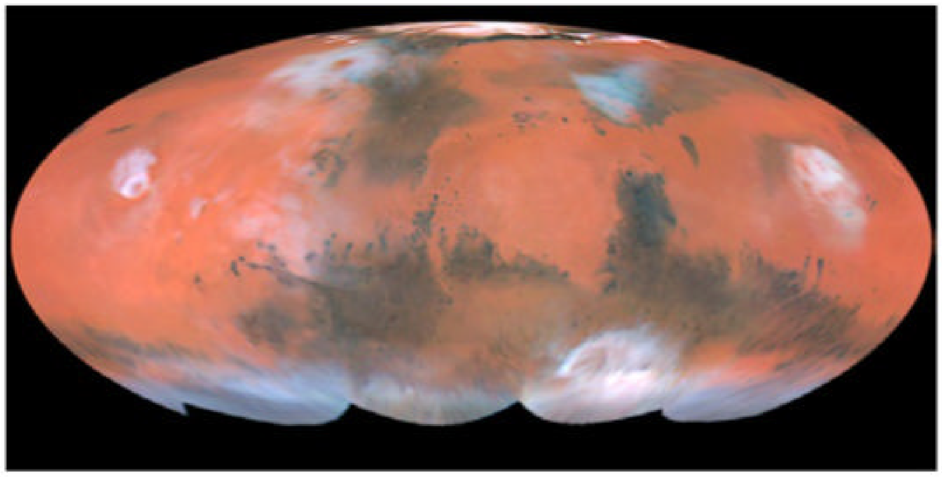
Thanks to humanity's legion of robotic martian surveyors, we now know the rusty world was not always as arid and inhospitable as it is today. Because Mars is covered in networks of valleys and deltas that once carried rivers and fed long-lost lakes, scientists are confident liquid water once flowed freely across its surface. Rock and soil samples plucked right off the ground and analyzed on the spot back up that history, as many could have only formed in the presence of copious liquid water.

Although rovers tend to get most of the credit, orbiters have contributed just as much to our understanding of Mars' past. For instance, a 2018 study published in *Geology* based on high-resolution photos taken by NASA's Mars Reconnaissance Orbiter analyzed dozens of martian outlet canyons carved out by flowing water that snaked from ancient lakes. The researchers found that the topography of the many outlet canyons matches what they'd expect if they had all rapidly formed during a massive and catastrophic flooding event some 3.5 billion years ago.

Such evidence for vast amounts of liquid water having once flowed on Mars is largely why NASA's latest rover, Perseverance, is currently searching for signs of ancient martian life. But the possibility of past life isn't the world's only appeal. Compared to Mercury, Venus, and the giant planets, Mars could offer a somewhat suitable place for humanity to eventually set up shop — if, of course, we can harvest and make what we need there.



LEFT: NASA's Curiosity rover poses for a selfie in front of a 20-foot-tall (6 m) rock formation named Mont Mercou. This panorama was stitched together from a total of 71 images taken by two cameras mounted on the rover's arm and head. NASA/JPL-CALTECH/MSSS



BELOW: The Hubble Space Telescope's Wide Field and Planetary Camera 2 snapped the four images used to create this nearly global, full-color map of Mars. STEVE LEE (UNIVERSITY OF COLORADO)/JIM BELL (CORNELL UNIVERSITY)/MIKE WOLFF (SPACE SCIENCE INSTITUTE)

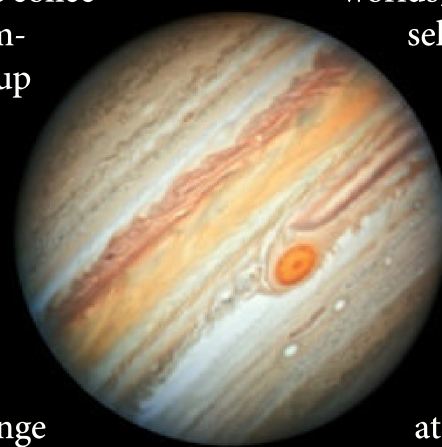
STATS

Mass: 0.11 Earth masses
Diameter: 4,220 miles (6,790 km)
Surface temperature: 68 F (20 C) to -243 F (-153 C)
Rotation period (day): 24 hours 37 minutes
Orbital period (year): 687 Earth days
Moons: Phobos and Deimos

The Viking Orbiter provided the images used to create this global color map of Mars' scarred and ice-capped surface, which is seen at a resolution of about 0.6 mile (1 km) per pixel. NASA/JPL-CALTECH/USGS

JUPITER

Like Mars, Jupiter has received a lot of attention during the era of space exploration. That began with Pioneer 10, which flew by the gas giant in 1973. It was rapidly followed by Pioneer 11 (1974), Voyager 1 (1979), and Voyager 2 (1979). Each of these missions had their own scientific objectives, but collectively, they revealed a world of confounding complexity. The Pioneer probes took the first close-up shots of the behemoth's storm-strewn atmosphere, as well as studied its super-charged radiation belts and powerful magnetic field (the strongest of any planet in our solar system). The Voyagers provided improved views of the king of planets, tracking Jupiter's alternating bands of bright white zones and darker brown belts. This new perspective revealed strange atmospheric behavior that models did not predict, including eddies churning in the clouds and a pair of colliding oval storms that ejected streamers upon merging. Such unexpected sights left the imaging team "happily bewildered."



Jupiter's swirling bands are created by differences in the thickness, height, and composition of its icy clouds. The colorful bands flow in opposite directions at various latitudes; the lighter bands hold thicker clouds and stretch higher than the darker bands. This image of the gas giant was captured by Hubble in June 2019. NASA/ESA/A. SIMON (GSFC)/M.H. WONG (UNIVERSITY OF CALIFORNIA, BERKELEY

In the decades since, NASA has continued slinging spacecraft at Jupiter. The Galileo mission included an orbiter and the first-ever probe to dive into the atmosphere of one of the outer planets. As the Galileo probe plunged into Jupiter's swirling bands of multicolored clouds, it transmitted back data for nearly 58 minutes before finally succumbing to face-melting temperatures of almost 25,000 degrees Fahrenheit (14,000 degrees Celsius). Still, Jupiter's beautifully chaotic atmosphere — including its famous Great Red Spot, a storm the size of Earth that's been brewing for centuries — isn't the only intriguing aspect of the jovian system.

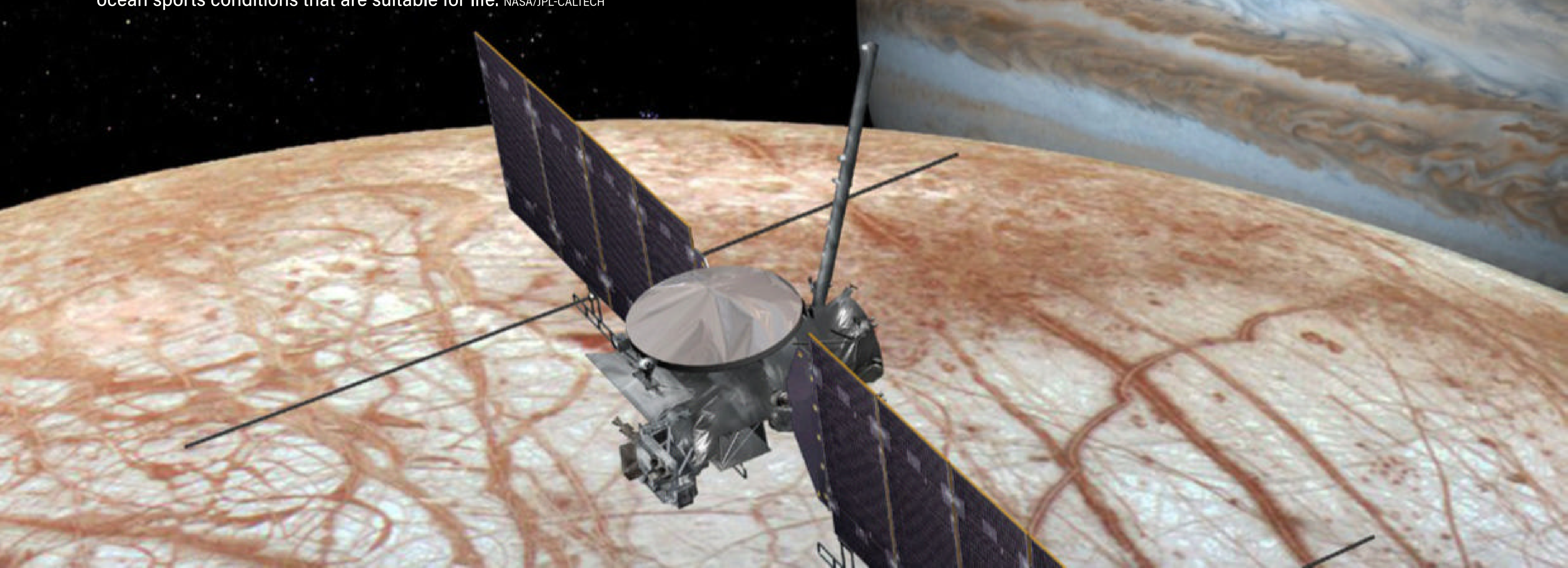
Jove's natural satellites total nearly four score and run the gamut in size, ranging from tens to thousands of miles wide. But of these moons, four truly stand above the rest. These are Jupiter's Galilean moons: Io, Europa, Ganymede, and Callisto. The more we learn about these surprisingly complicated worlds, first recognized as moons by Galileo Galilei himself in March 1610, the more intriguing they get. Io is the most volcanically active world in the solar system, thanks to Jupiter's immense gravity creating tides in Io's solid surface that reach some 300 feet (100 m) tall. Europa's surface, on the other hand, is mostly water ice and might even hide an underground global ocean of slushy water. Ganymede, which is wider than Mercury and the largest moon in the solar system, generates its own internal magnetic field. Callisto, meanwhile, shows little evidence of recent resurfacing, which means its heavily cratered face likely preserves a record of stray detritus streaming through the early solar system.

These intriguing features are just some of the reasons the European Space Agency (with NASA as a partner) plans to launch the JUICE (JUpiter ICy moons Explorer) mission in 2022, which will see an orbiter reach the jovian system in 2029. Once there, JUICE will spend several years closely scrutinizing Ganymede, Callisto, and Europa — while also evaluating the potential of these watery worlds to harbor life.

STATS

Mass: 318 Earth masses
Equatorial diameter: 88,850 miles (143,000 km)
Average temperature: -162 F (-108 C)
Rotation period (day): 9 hours 56 minutes
Orbital period (year): 11.9 Earth years
Moons: At least 79 moons

NASA's Europa Clipper spacecraft, seen here in this artist's concept, is expected to launch to Jupiter aboard a SpaceX Falcon Heavy rocket in October 2024. Once in orbit, it will conduct a series of flybys of Europa, using a suite of science instruments to study the moon's surface and composition, measure the thickness of its icy crust, and even investigate whether the world's subsurface ocean sports conditions that are suitable for life. NASA/JPL-CALTECH



SATURN

The surreal *je ne sais quoi* of Saturn has captivated observers for centuries. That's largely because the world's stunning rings span some 170,000 miles (274,000 kilometers), or about 2.5 times the width of the planet itself. But get this: They might be as little as 30 feet (10 meters) thick in some places. So, when the planet is tilted just so to our line of sight, presenting its ring system side-on, those rings all but vanish from our view.

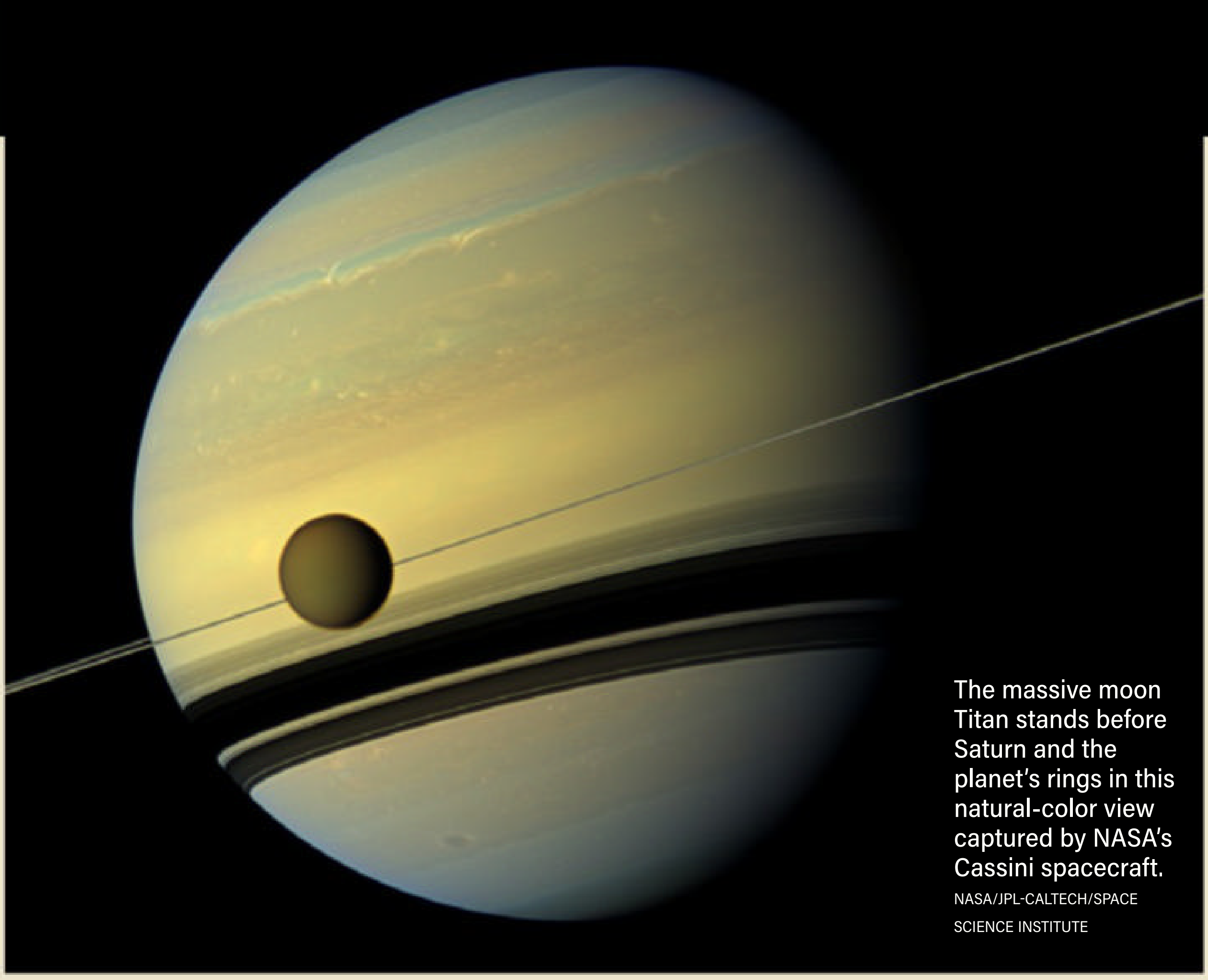
The world's glimmering rings are made of countless pieces of dirty water ice that range in size from dust grains to mountains. Although it's unclear exactly how or when the rings formed, Cassini data indicate they are the result of a moon (or moons) being torn asunder 10 million to 100 million years ago. Considering the planets are some 4.5 billion years old and scientists expect the rings to last just another couple of hundred million years, we're quite fortunate to bear witness to this relatively brief celestial show.

Launched in 1997, the Cassini spacecraft spent some 13 years exploring all Saturn has to offer (despite mission planners initially banking on only four years of scientific study there). During that time, the craft returned thousands of awe-inspiring images, tracked Saturn's seasonal changes, analyzed its icy rings, and studied its raging storms, including the massive hexagonal hurricane that churns around the world's north pole. As part of Cassini's Grand Finale in 2017, the spacecraft even skirted past the inner edge of Saturn's rings before plunging into the gas giant's multilayered, ammonia-laced clouds. During its final orbits, Cassini not only sampled ring particles that are magnetically drawn into Saturn's atmosphere, but also created highly detailed maps of the world's gravitational and magnetic fields.

While exploring the Saturn system, Cassini also dropped off an ESA-built lander named Huygens near the intriguing moon Titan. Despite all odds, the craft managed to survive its descent through the moon's dense clouds, revealing one of the most surprisingly Earth-like worlds yet found in our solar system.

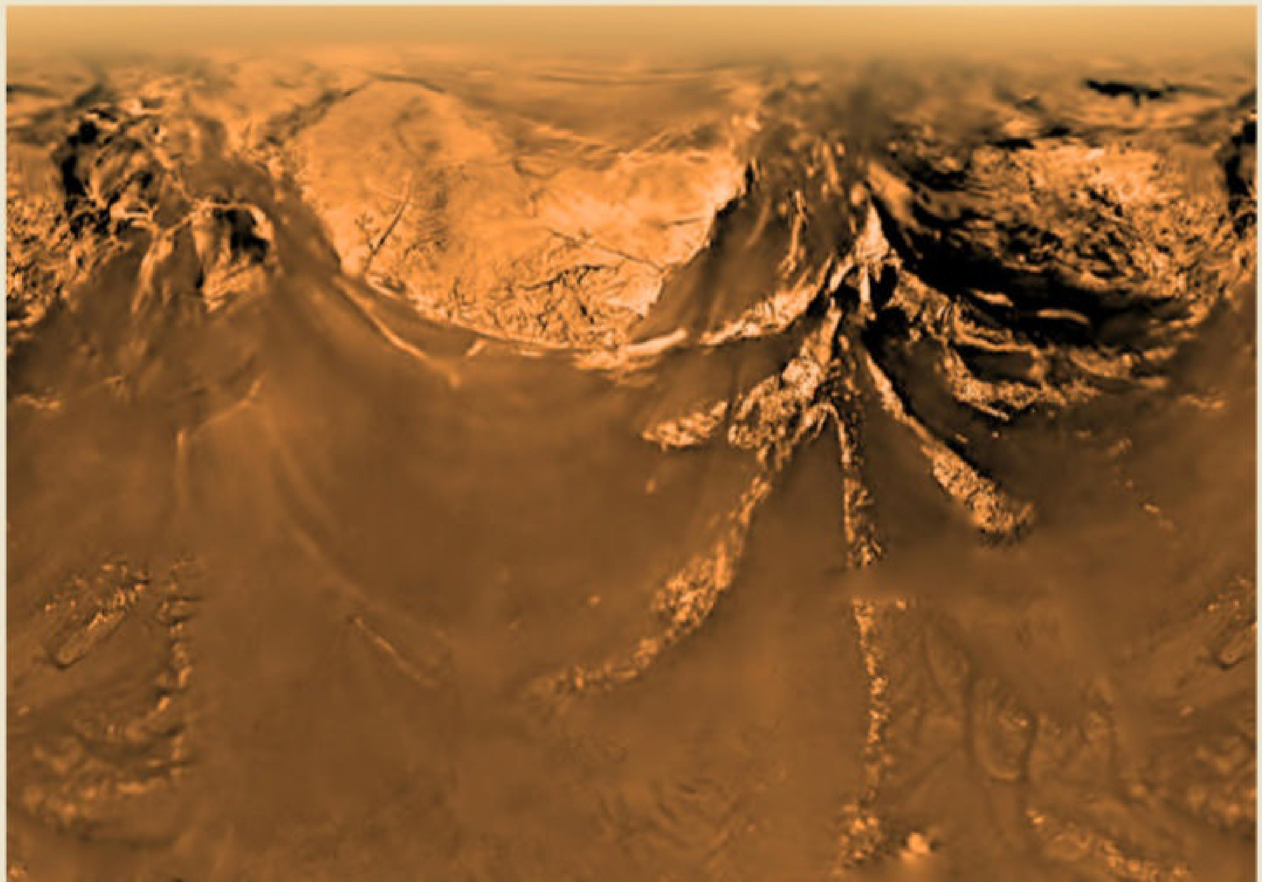
STATS

Mass: 95 Earth masses
Equatorial diameter: 74,900 miles (120,500 km)
Average temperature: -218 F (-139 C)
Rotation period (day): 10 hours 39 minutes
Orbital period (year): 29.5 Earth years
Moons: At least 82 moons



The massive moon Titan stands before Saturn and the planet's rings in this natural-color view captured by NASA's Cassini spacecraft. NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE

On July 19, 2013, Saturn eclipsed the Sun from Cassini's vantage point. This majestic mosaic of 141 images is only slightly enhanced and hides a surprise. Can you spot our blue home planet just beneath Saturn's rings at lower right? NASA/JPL-CALTECH/SSI



Cassini carried with it the ESA's ambitious Huygens lander, which floated through Titan's atmosphere and landed (after bouncing) on the surface in January 2005. This mosaic shows Huygens' view of Titan's complex terrain from an altitude of about 6 miles (10 km). ESA/NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA

URANUS

Unlike the gas giants Jupiter and Saturn, the solar system's more distant ice giants have largely received the cold shoulder from robotic spacecraft. But thanks to a fortunate planetary alignment that occurs only once every 175 years, NASA's ambitious Voyager 2 mission flew by the solar system's seventh planet, Uranus, in 1986.

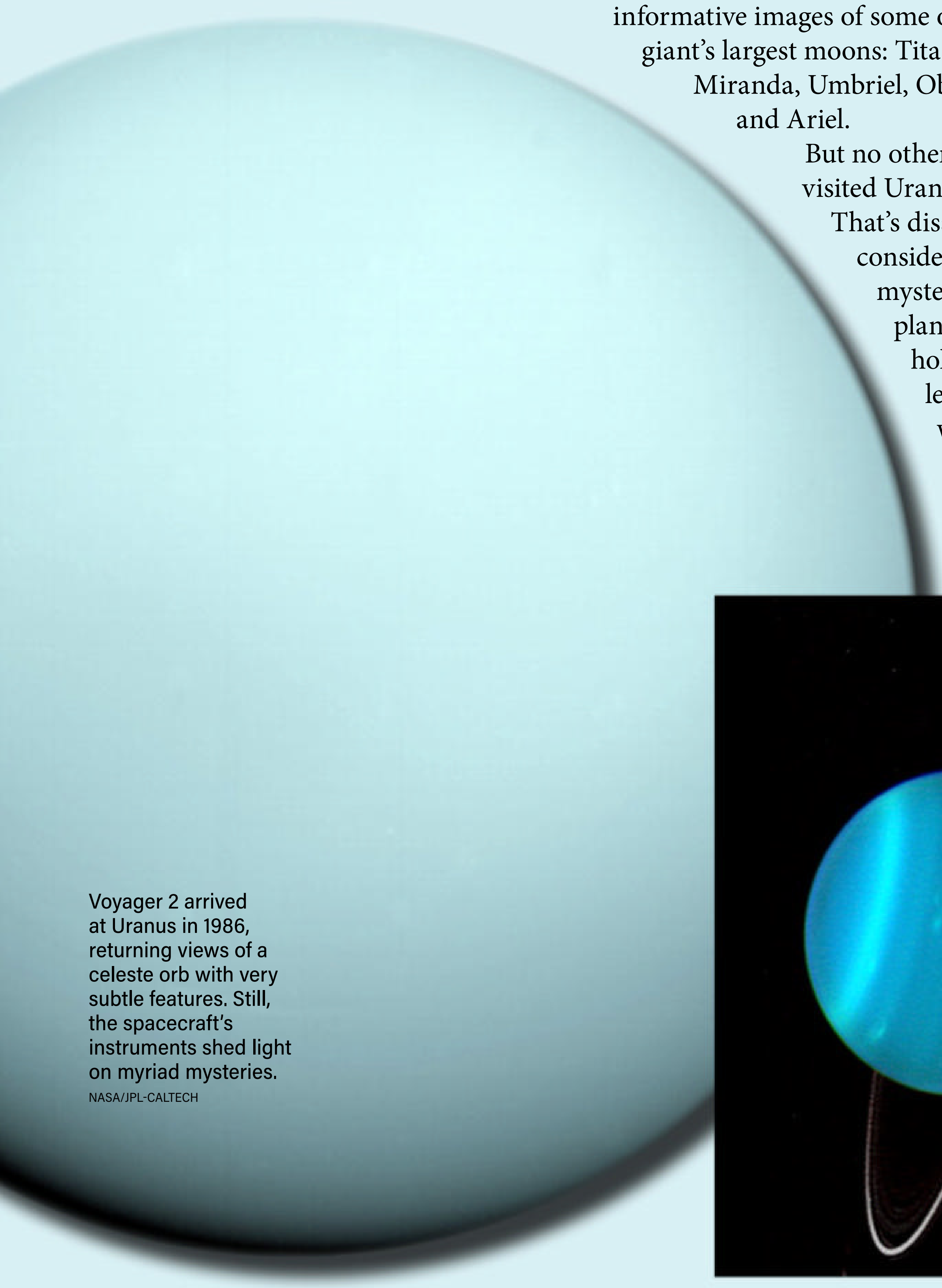
Like both its bloated inner siblings, Uranus hosts a ring system, though it is much fainter than that of Saturn. The rings around Uranus were initially discovered in 1977 by astronomers aboard the Kuiper Airborne Observatory, an airplane equipped with an infrared telescope. But Voyager 2 studied them in unprecedented detail. The mission also uncovered 10 new moons and clocked the planet's atmosphere zipping around the world at speeds approaching 450 mph (725 km/h). Before continuing on to Neptune, Voyager 2 also captured informative images of some of the ice giant's largest moons: Titania, Miranda, Umbriel, Oberon, and Ariel.

But no other craft has visited Uranus since. That's disappointing, considering all the mysteries the planet still holds. Not least of which: Why is Uranus' rotation axis tilted nearly 100° to the plane of the solar system, making it orbit the Sun not like a spinning top, but more like a rolling ball? No matter the cause (the leading theory is an ancient planetary collision), we do know that this unique orientation gives Uranus the most extreme seasons in the solar system. One pole is bathed in constant sunlight while the other is veiled in darkness for some 21 years at a time. Uranus' magnetic field is also lopsided, tilted some 60° relative to its spin axis, so the planet's rotation twists its magnetic field lines into a bizarre corkscrew shape.

Another unresolved mystery about Uranus is its structure. The blue-green hue of its swirling atmosphere (primarily made of hydrogen and helium) is the result of trace methane gas, which more readily absorbs red light. But as you venture deeper beneath the planet's cloud tops, things get murkier. Scientists think that about 80 percent of the planet exists in the form of hot and dense mantle layers composed of super-pressurized water, ammonia, and methane fluids, which surround a small core of icy rock. The jury's still out on that, however. Maybe another mission to Uranus is in order?

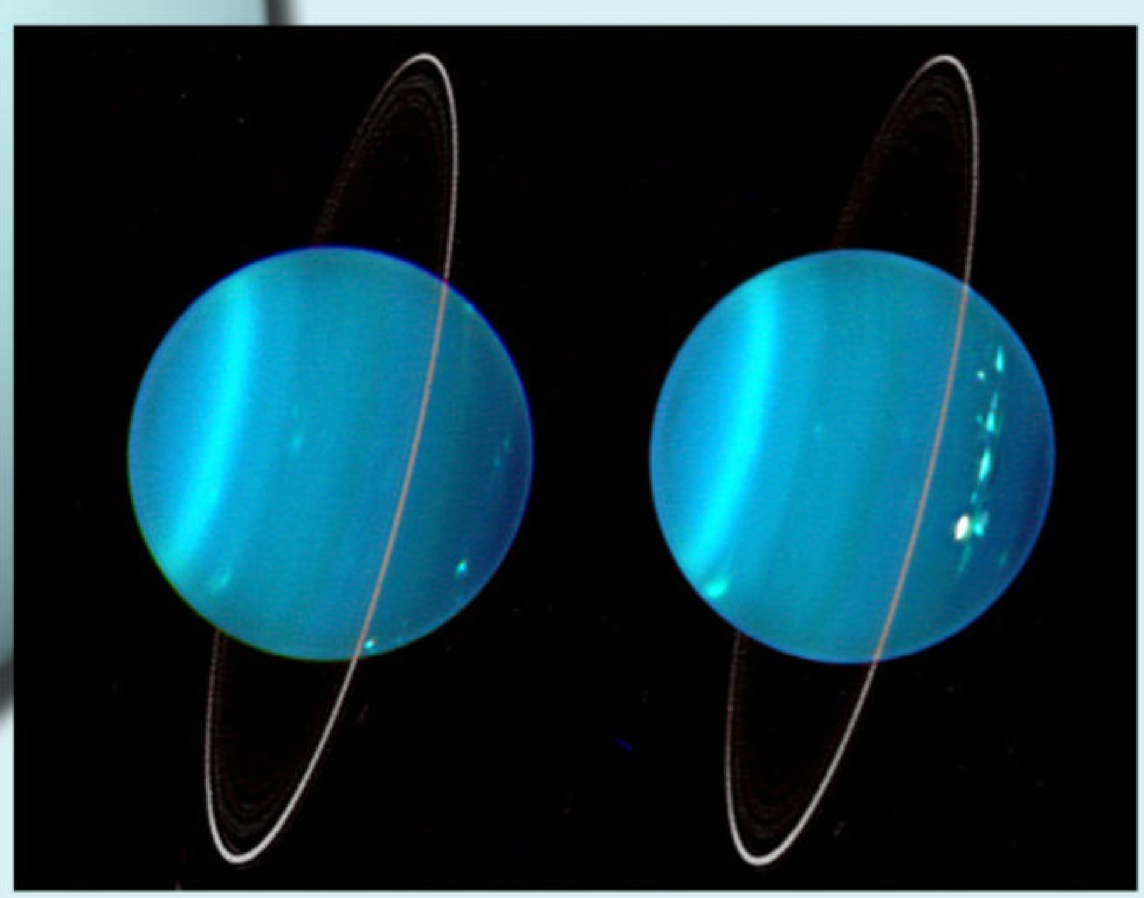
STATS

Mass: 14.5 Earth masses
Equatorial diameter: 31,760 miles (51,120 km)
Average temperature: -323 F (-197 C)
Rotation period (day): 17 hours 15 minutes (retrograde)
Orbital period (year): 84 Earth years
Moons: At least 27 moons



Voyager 2 arrived at Uranus in 1986, returning views of a celeste orb with very subtle features. Still, the spacecraft's instruments shed light on myriad mysteries. NASA/JPL-CALTECH

BELOW: Thanks to adaptive optics, the Keck Telescope obtained these infrared views of the two hemispheres of Uranus and its faint ring system in 2004. The ice giant's south pole is facing left in both images. W.M. KECK OBSERVATORY/LAWRENCE SROMOVSKY (UNIVERSITY OF WISCONSIN-MADISON)



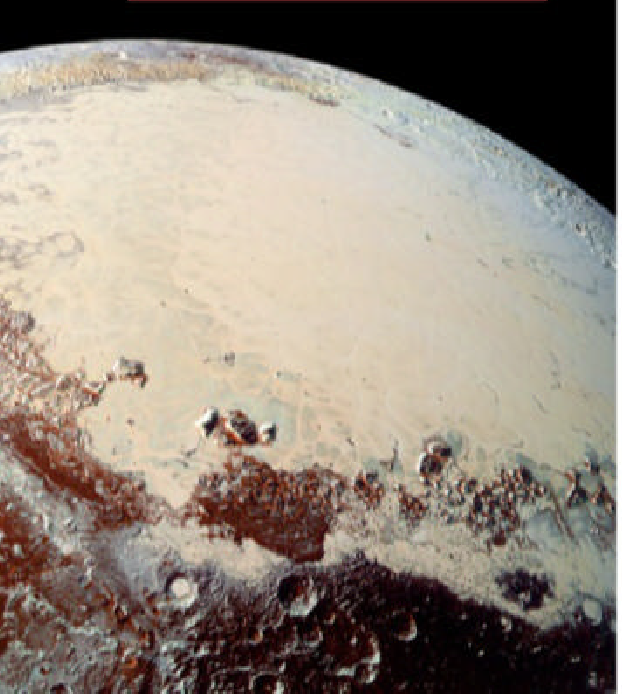
Honorable mention: PLUTO

Pluto, despite what the International Astronomical Union says, is still a planet in the minds of many. And whether it's a planet or dwarf planet, nearly all agree Pluto is a fascinating world. Covered in plains of nitrogen ice and textured with mountain ranges of frozen water, this demoted world was closely studied less than seven years ago by NASA's New Horizon spacecraft.

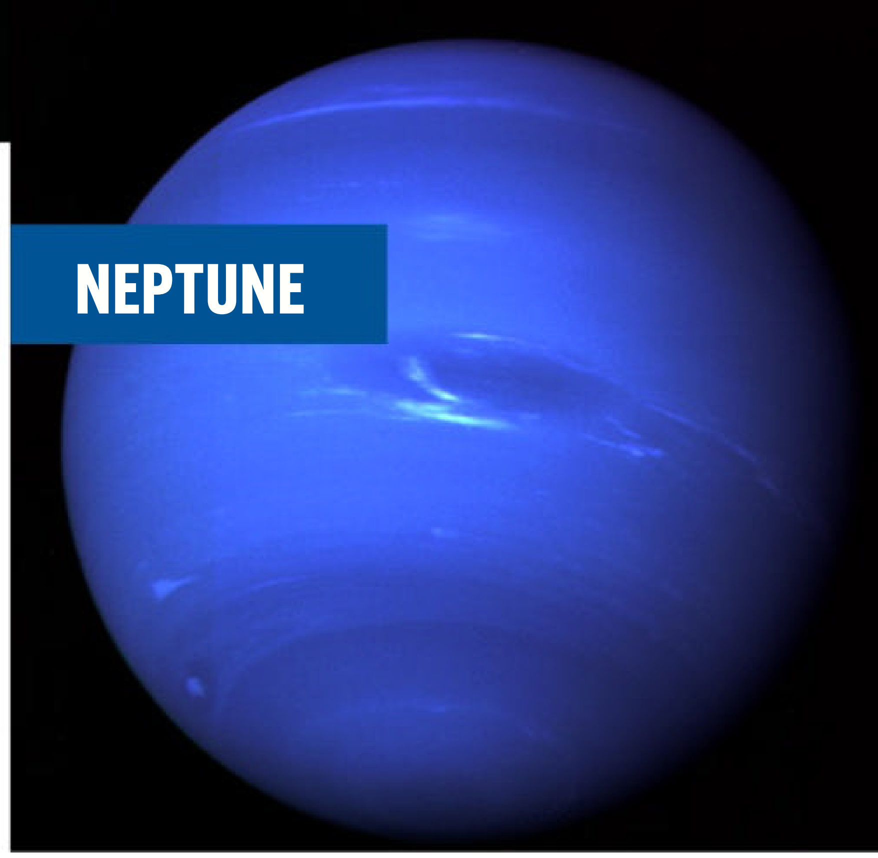
BELOW: The western lobe of Pluto's "heart," Sputnik Planitia, was imaged by New Horizons during its flyby in 2015. Thanks to the spacecraft, astronomers now know the area is a craterless region rich in slowly shifting nitrogen, methane, and carbon monoxide ices. NASA/JHU-APL/SWRI

STATS

Mass: 0.002 Earth masses
Diameter: 1,480 miles (2,380 km)
Surface temperature: -387 F (-233 C)
Rotation period (day): About 6.4 Earth days (retrograde)
Orbital period (year): 248 Earth years
Moons: Charon, Hydra, Styx, Kerberos, Nix



NEPTUNE



Taken by Voyager 2 at a distance of some 4.4 million miles (7.1 million km), this view of Neptune features a temporary great dark spot at center (and a companion bright smudge below that). First seen in 1989, this spot had disappeared by the time Hubble observed the world in 1994, though it did see a similar feature in the ice giant's northern hemisphere. NASA/JPL-CALTECH

You'd expect the solar system's most distant planet, which is some 30 times farther from the Sun than Earth, to be pretty chill. But although aquamarine Neptune is absolutely cold, it's definitely not calm.

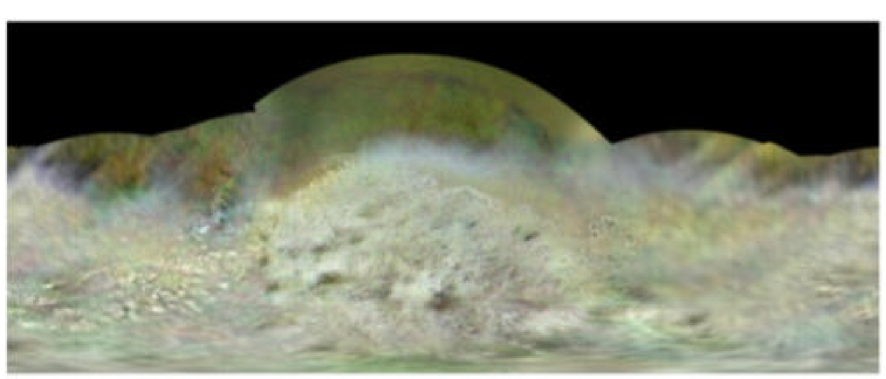
Neptune sports the strongest winds in the solar system, which can whip across the gaseous planet at speeds up to 1,200 mph (2,000 km/h). That's about 1.5 times the speed of sound! Plus, about half the time, the world hosts at least one giant anticyclonic storm called a great dark spot, which are thought to take on a shadowy appearance because their strong winds tear a hole in Neptune's methane-laced cloud deck. However, unlike Jupiter's seemingly immortal Great Red Spot, Neptune's fierce storms usually pop up and disappear within just a few years.

STATS

Mass: 17.15 Earth masses
Equatorial diameter: 30,800 miles (49,500 km)
Average temperature: -330 F (-201 C)
Rotation period (day): 16 hours 7 minutes
Orbital period (year): 165 Earth years
Moons: At least 14 moons

Let's not forget Triton, Neptune's largest satellite, either. It's the only large moon in the solar system that orbits in the opposite direction of its host planet's spin. Scientists think Triton might have this so-called retrograde orbit because it was captured from the Kuiper Belt, a vast disk of icy remnants from the early solar system, orbiting beyond Neptune. But no matter its origin, Triton is a surprisingly active world. Thanks to Voyager 2, we know this frosty wonderland is home to a variety of intriguing features: Its frozen nitrogen crust is adorned with rounded mounds created by icy lava flows, as well as vast, smooth volcanic plains. It's also speckled by fewer craters than expected for an object its age, suggesting its surface is being rejuvenated. Voyager even found that Triton hosts active ice volcanoes that spew frozen nitrogen as high as 5 miles (8 km) above the moon's south pole.

Voyager 2 observed the surface of Neptune's moon Triton, which is composed mainly of nitrogen ice, as it flew by the world in 1989. This contrast-enhanced map approximates Triton's true colors and has a resolution of 1,970 feet (600 m) per pixel. NASA/JPL-CALTECH/LPI



I'll leave you with one final thought: In the decades since Voyager 2 carried out the only mission to the ice giants, scientists have uncovered thousands of exoplanets outside our solar system. And despite planetary formation models suggesting ice giants should be relatively rare, exoplanetary evidence suggests they are surprisingly common. So, although our ice giants may seem too alien to matter, exploring them might help us better understand what it took to set the stage for life here on Earth — or even beyond.

Jake Parks *is associate editor of* Astronomy.

How to SWALLOW

A doomed star makes a close approach to a black hole in this artist's concept. The extreme tidal forces exerted by the black hole's gravity are tearing the star apart. MARK A. GARLICK

A STAR

When a star disappears down the throat of a black hole, the flash is just the start of the show.

BY YVETTE CENDES

I wake up to a chime from my smartphone. Bleary-eyed, I check it — and jolt awake upon seeing an automated email from the MeerKAT radio telescope in South Africa.

The subject line reads: "AT 2018xxx 2hr has been completed." The message tells me that while I was sleeping, MeerKAT observed a target for two hours and, after some initial image processing, the observation is now ready for me in the archives. All that remains for me, half a world away in Cambridge, Massachusetts, to do is go online and download it.

The lure of potential discovery wakes me up more than a pot of coffee ever could. *This could be it!* A modern radio astronomer does not have to travel to faraway lands to collect the data herself — arguably less romantic. But the thrill of anticipation and discovery stays the same, no matter where on Earth you are.

I drum my fingers while waiting for my laptop to load the image, excitement mounting as I wonder what I'm about to see. There are a lot of stars and galaxies in this patch of sky, but that's just window dressing. The *real* excitement would be overlooked by the untrained eye: a tiny collection of unobtrusive pixels in the middle of the image. It is light from a star's final gasp as a supermassive black hole at the center of a galaxy gets violent, pulling the star apart and cannibalizing it. A tidal disruption event (TDE), as these occurrences are called, is one of the most energetic

The 64-dish array of the MeerKAT radio telescope lies in South Africa's Karoo region, in the Northern Cape province. SOUTH AFRICAN RADIO ASTRONOMY OBSERVATORY (SARAO)

and luminous events in the universe. But few are easy to find, and even fewer emit the radio waves crucial to understanding them. Each new discovery is precious.

And in just a few more minutes, I will be the only person on Earth to know whether, for this source, a radio signal exists. I drum my fingers faster.

Torn apart

The story of a TDE begins at the heart of a galaxy, near the edge of a supermassive black hole millions or billions of times the mass of the Sun. Astronomers now think that practically every large galaxy has one such black hole at its center. These gravitational monstrosities play a key role in the formation of their host galaxies and wield huge influence on their surroundings.

Black holes are famously so dense that even light cannot escape their gravity. But despite popular conceptions, they don't actually suck material in any more than the Sun sucks in the planets that orbit it. For example, if the Sun were to suddenly compress into a black hole, it would shrink to just 4 miles (6 kilometers) across, yet the planets would continue to orbit as they currently do because its mass wouldn't change.

The star deforms from its usual sphere into an oval, and then into a long, thin stream. This process is called spaghettification.

The gravity of a black hole works the same way. When astronomers look to the center of our own Milky Way Galaxy, we see over a dozen stars orbiting a common point where our galaxy's supermassive black hole, called Sagittarius A* (Sgr A*), resides. In fact, astronomers have been observing Sgr A* for so long that they have seen the innermost star, S2, complete one full orbit, which takes 16 years. After establishing S2's orbital parameters, researchers applied Kepler's third law of planetary motion to calculate the mass of Sgr A*, which clocks in at a whopping 4 million solar masses. While the final calculation was simple, the work to get the data over so many years was not — in fact, it won astronomers Andrea Ghez and Reinhard Genzel the 2020 Nobel Prize in physics.

S2 looks like it's on a stable orbit for now, but researchers estimate that thousands of stars, including stellar remnants like neutron stars and white dwarfs,

also orbit Sgr A*. When two of these objects have a close encounter, their gravity perturbs each other's orbits and they head out on new, altered trajectories. Most of these orbits remain stable, or perhaps fling the star outward from the center of the galaxy. But on rare occasions, a star's new orbit sends it inward on a collision course with disaster.

As the doomed star approaches the supermassive black hole, it begins to experience tidal forces: Because gravity is stronger closer to an object, the black hole pulls more strongly on the star's near side than its far side. Eventually, when the star reaches a certain distance from the black hole — the tidal radius — the difference in force from one side to the other becomes greater than the star's self-gravity holding it together.

When this happens, "the star gets stretched along its direction of motion," explains Enrico Ramirez-Ruiz, an astrophysicist at the University of California, Santa Cruz, who specializes in TDE theory. The star deforms from its usual sphere into an oval, and then into a long, thin stream. This process is called spaghettification. As it occurs, the star's density decreases and fusion at its core stops altogether. Though a star may take millions of years to form and shine for billions more, this final unraveling takes just a few hours.

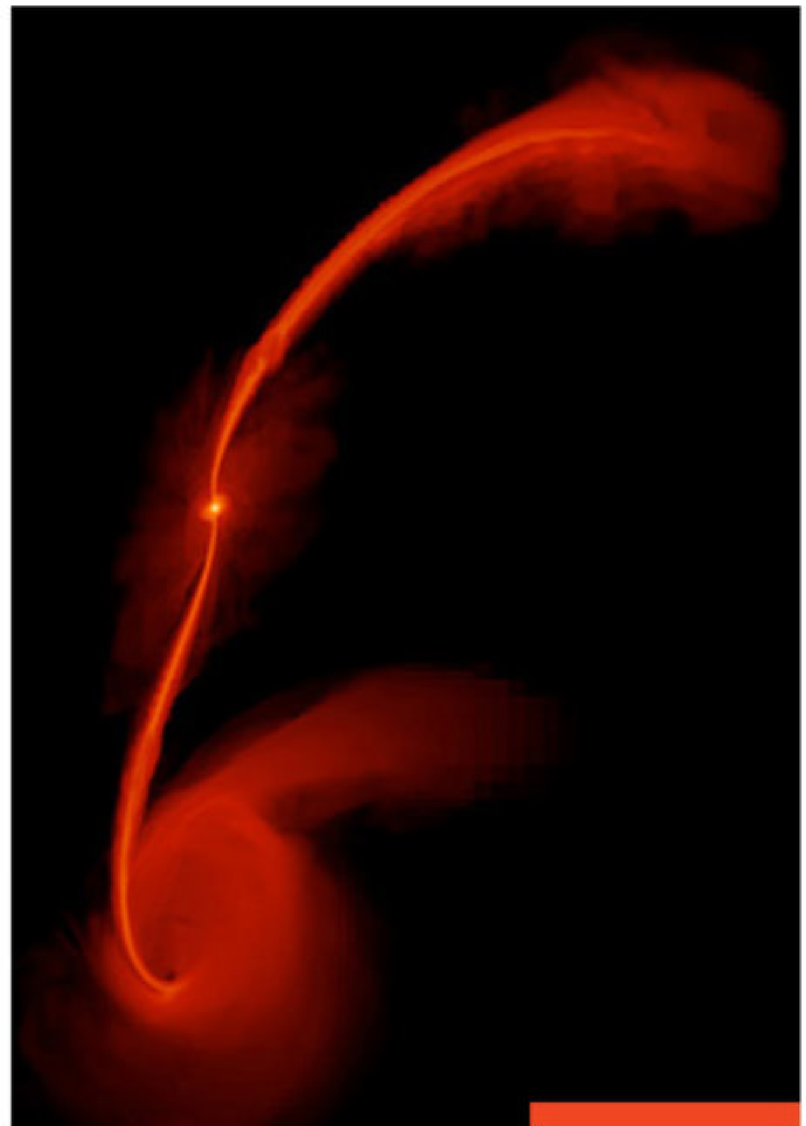
The hunt for TDEs

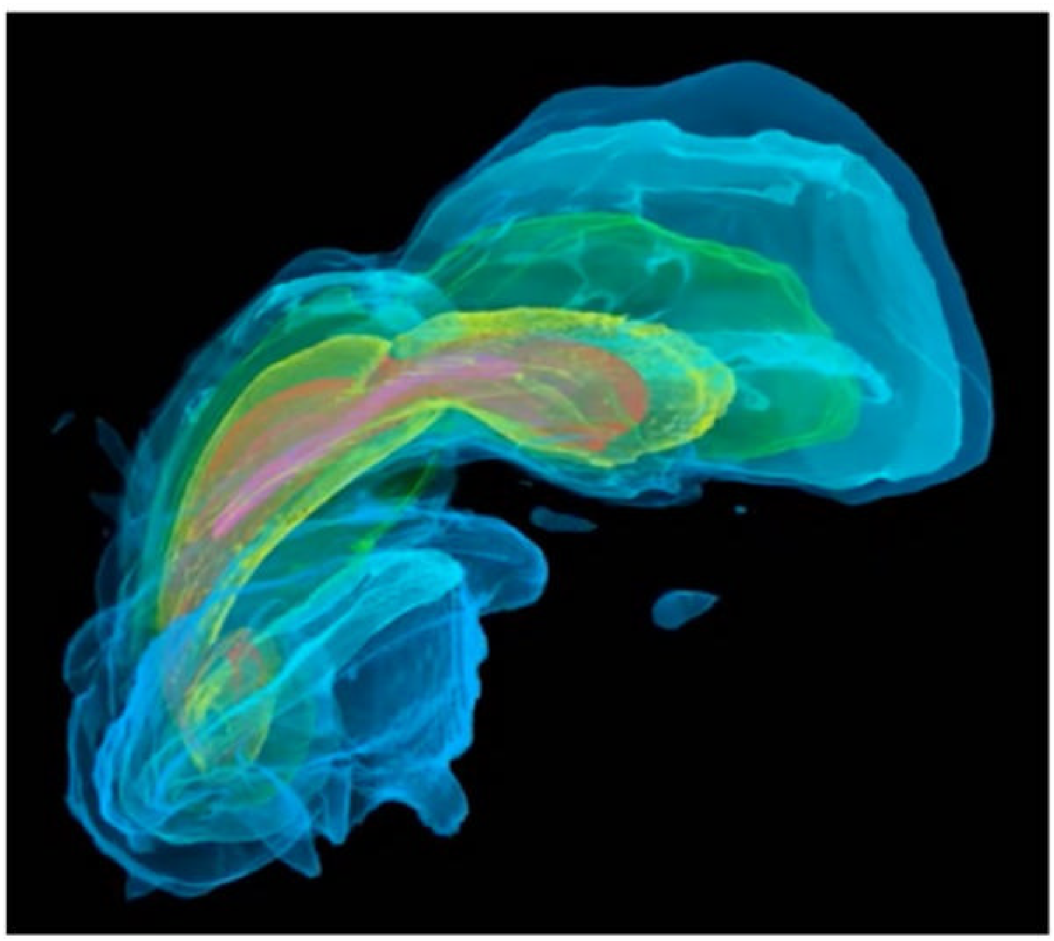
What happens next? "Half the star's material falls in and forms an accretion disk around the star," explains Ramirez-Ruiz, "and half gets ejected." The material in the disk falls onto the black hole and feeds it, powering a luminous flare that can be seen at vast distances before slipping past the black hole's event horizon (where light can no longer escape).

At first glance, these dazzling events can resemble a supernova — a massive star that explodes at the end of its life when its fuel is exhausted. To distinguish TDEs from supernovae, astronomers keep an eye out for two things. First, they look for a bright flare at the center of a galaxy whose supermassive black hole was previously dormant. Then, they break down the light by wavelength and study its spectrum to see what elements it contains. Unlike in a supernova, the elements observed in a TDE flare are similar to those in main sequence stars that are still burning strong. If your flare fits both criteria, you have a potential TDE on your hands!

Astronomers spotted the first TDE candidates in the 1990s. In recent years, finding them has gotten easier thanks to automatic sky surveys that scan the night sky for transient objects — signals that change in the sky over time instead of remaining constant. Still, to date, we have only observed about 100 TDEs.

That's because TDEs are rare. Astronomers estimate that a galaxy like the Milky Way has a TDE no more than once every 100,000 years. Supernovae, on the other hand, occur in a galaxy our size roughly once a century.





ABOVE: The tidal forces that act upon a star near a black hole rip it apart in a process called spaghettification, depicted in this simulation. As matter is pulled off the star, it forms dramatic tidal tails and, eventually, an accretion disk (at bottom left). J. GUILLOCHON AND E. RAMIREZ-RUIZ

LEFT: This simulated view shows the density in the accretion disk, with denser regions in red and less-dense regions in blue. J. LAW-SMITH AND E. RAMIREZ-RUIZ

An incredible picture

Arguably the most famous TDE to date occurred in 2011, when NASA's Neil Gehrels Swift Observatory detected a strange burst of radiation from the center of a galaxy 3.8 billion light-years away. Swift was launched in 2004

Relativistic jets shoot out from the supermassive black hole at the heart of the galaxy Centaurus A in this photo-illustration, plowing into surrounding material. ESA/HUBBLE, L. CALÇADA (ESO)

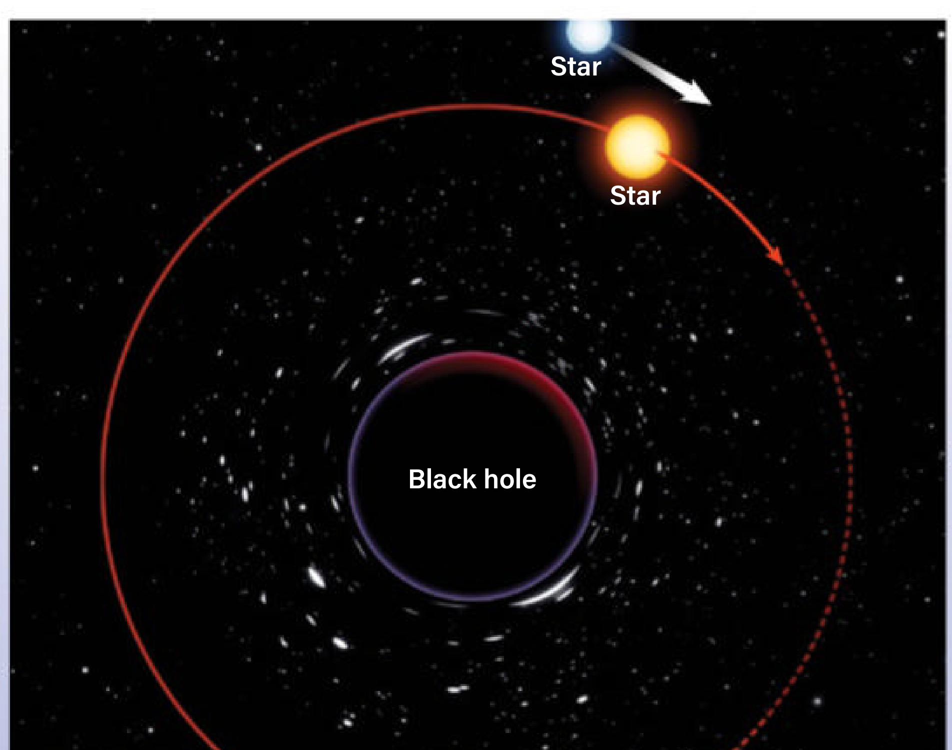
to study gamma-ray bursts — immensely energetic bursts of radiation that occur during a supernova or a neutron star merger. But unlike those bursts, which last no more than a few minutes, this radiation just kept going. "It was unlike anything we had seen before," recalls Joshua Bloom, an astronomer at the University of California, Berkeley, who was a lead investigator on the signal.

Soon, telescopes spanning the entire electromagnetic spectrum were pointed at Swift J1644+57, as the event came to be known. Different physical processes emit different kinds of radiation, and often the key to unraveling an astronomical mystery lies in observing as many wavelengths as possible.

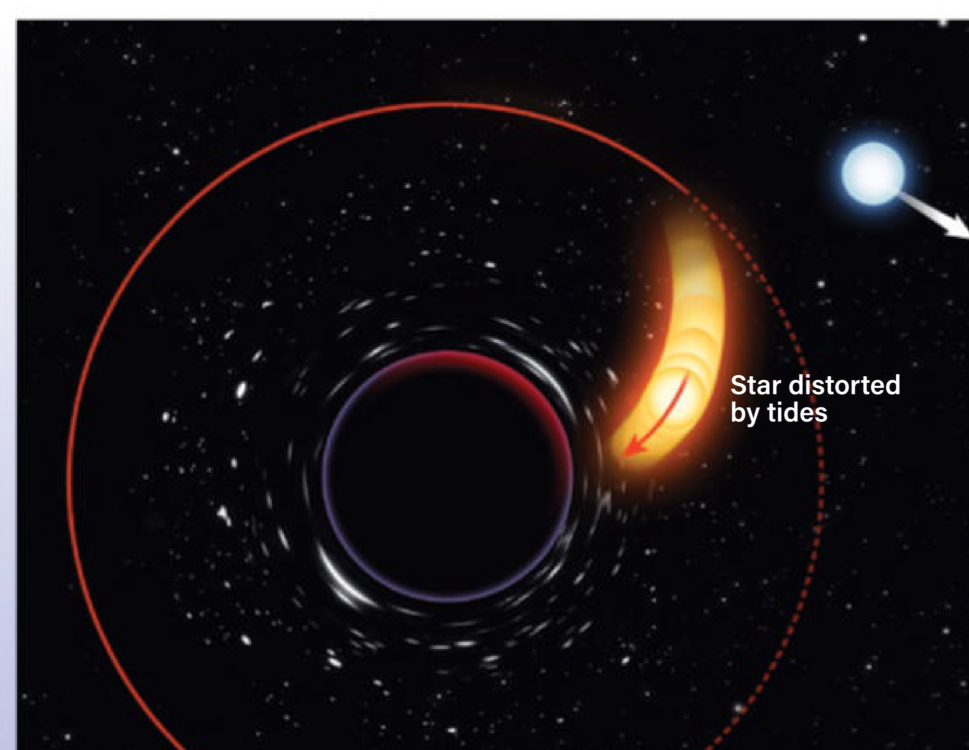
An incredible picture emerged: A TDE had occurred around a previously dormant black hole and, as part of this process, the TDE had somehow launched a jet of material traveling at near light-speed, so fast that the laws of relativity must be considered. This relativistic jet was aimed directly at Earth — and astronomers were staring directly into the beam. "It was one of my only times as an astronomer where I had an 'ah-ha!' moment, and all the little pieces started coming together in my head," recalls Bloom. "We didn't have all the details yet, but observationally and theoretically it seemed to click."

In X-ray wavelengths, astronomers noticed a consistent rising and falling pattern in the TDE's brightness. They realized these were flare-ups from shredded material falling into the black hole, constantly fueling the jet. Another key piece of information came from radio wavelengths. By measuring the signal intensity over multiple frequencies, astronomers could extract a range of information. This included the energy in the jet, as well as the radius of the blast wave that created the radio signals, and even the density of

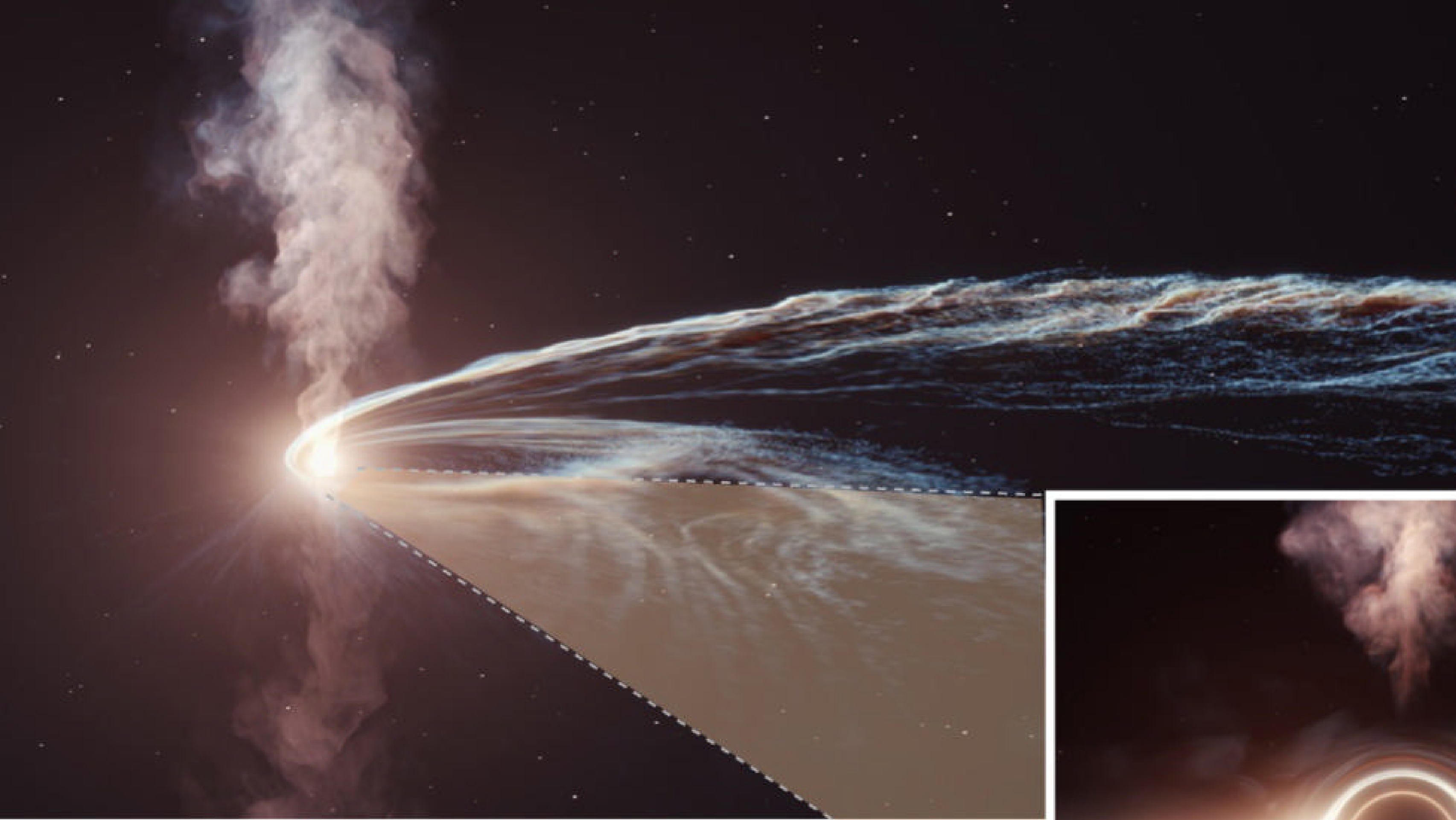
THE DEATH OF A STAR



1 Tidal disruption events begin with a star orbiting a supermassive black hole at the heart of a galaxy. If it makes a close encounter with another star, it can be thrown into a death plunge towards the black hole.



2 As the star nears the black hole, tidal forces begin to grow, distorting the star — the process of spaghettification.



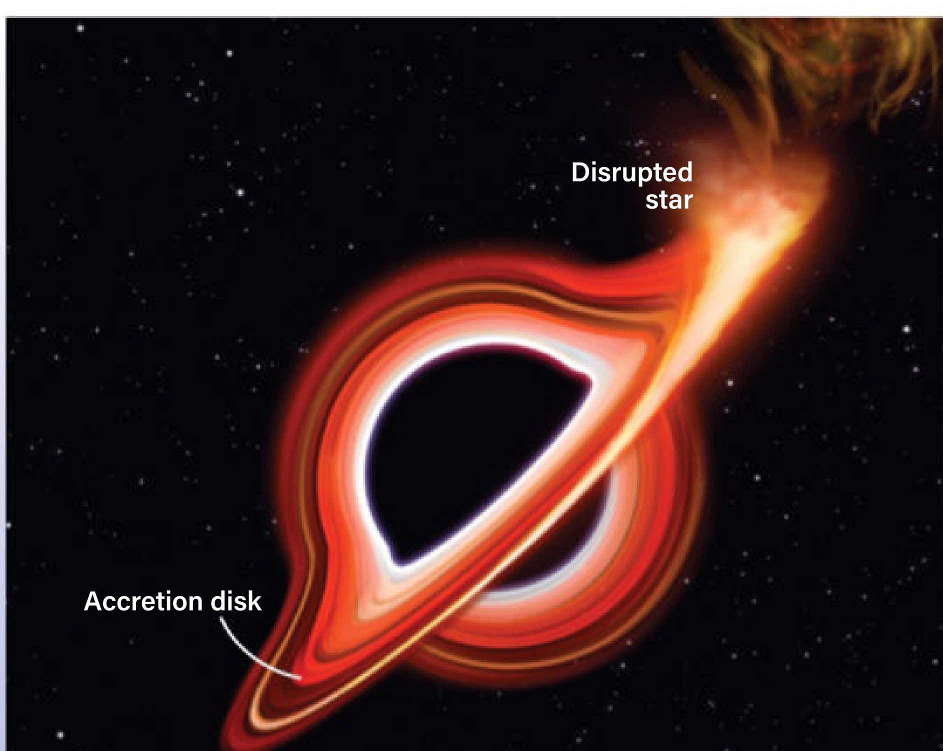
A thin stream of material from a tidally disrupted star is pulled into an accretion disk around a black hole in this illustration. DESY, SCIENCE COMMUNICATION LAB

In this close-up view, the remnants of the star are visible on the right side of the black hole. The ring of light that appears to surround the black hole is due to gravitational lensing — the gravity of the black hole bending light around it. DESY, SCIENCE COMMUNICATION LAB

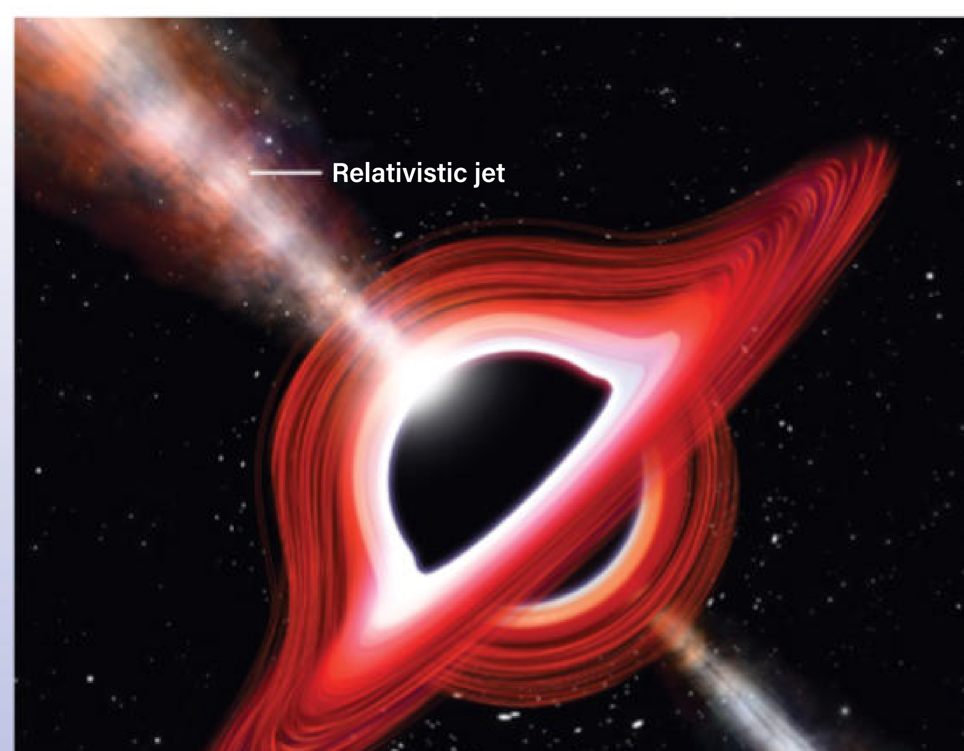
material it was plowing through. Finally, optical observations confirmed the location of the source itself: smack in the center of the host galaxy, where a supermassive black hole lurks.

Then, after about a year and a half of this activity, the X-ray signal suddenly dropped off precipitously, to the point where Swift could no longer detect it. Astronomers realized they'd just witnessed another incredible event — the jet turning off. Normally, relativistic jets from black holes last for thousands of years, at least. The fact that this one lasted for less time than it takes Mars to orbit the Sun was unprecedented, and a boon for astronomers working to unravel their mysteries.

Once the jet turned off, the shock wave from Swift J1644+57 slowly faded in energy. The X-ray emission is now long gone, but the blast still has enough power to send out radio waves that the Very Large Array (VLA) in New Mexico can study for 100 years. I know this because I did the analysis myself.



3 Eventually, the tidal forces become stronger than the star's self-gravity, ripping the star apart. Some of the disassembled stellar material forms an accretion disk around the black hole, and some of it is flung into space.



4 As matter swirls around the black hole, magnetic fields focus some of the material into a powerful jet, whose particles travel at close to the speed of light. This creates shock waves inside the jet that produce intense beams of X-rays and radio waves.

ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

I began my Ph.D. in astronomy in 2011, with an aim of specializing in transient radio astronomy. (I wanted to be a radio astronomer ever since I read *Contact* by Carl Sagan as a teenager, so this was an inevitable choice.)

When I heard about Swift J1644+57, I was impressed by how much information the radio signal contained. When I finished my Ph.D. and the opportunity arose to become a postdoctoral fellow at Harvard with the group that had done the initial Swift J1644+57 analysis, I jumped at it — and got to analyze the latest data on the TDE. Sure, I was years after the main fireworks and it was a ton of work, but I'd nevertheless stop every once in a while to marvel at my luck.

The great mysteries

When people hear I'm an astronomer, they'll often ask me what the most interesting unanswered question in the universe is. The honest answer is that it's frequently the thing I am working on at that moment — the more you research a subject, the more you come to appreciate its intricacies.

So here is the mystery about TDEs in general, and Swift J1644+57 in particular, that keeps me wondering: While it is the best-studied TDE on record, Swift J1644+57 was not predicted and is not at *all* like other TDEs we've seen. It was a thousand times more luminous in radio waves than other TDEs and over 10,000 times more energetic, thanks to its relativistic jet. On the other hand, in an "ordinary" TDE, material tends to flow out in all directions with energy levels similar to what we see in a supernova explosion — still awesome and impressive, of course, but a bit like comparing a conventional explosion to a nuclear bomb.

Coincidentally, Swift did spot two more jetted TDEs in 2011, but at much greater distances, so they couldn't be studied in detail. Otherwise, all the TDEs we've seen have fallen into the ordinary category. At this rate, it looks like just 1 percent of all TDEs launch a relativistic jet, and we still don't understand what makes those TDEs so special. Perhaps the star unbinds particularly fast, or the magnetic fields around the black hole are extraordinarily high — but without more events, it's hard to know for sure.

Another mystery about TDEs that keeps me wondering is that while we know a lot of the material falls into the black hole, lots of it doesn't. "We know supermassive black holes are messy eaters," my collaborator Kate Alexander, an astronomer at Northwestern University, likes to joke. How the leftover material interacts with the surrounding environment is still an open question.

If we are going to understand TDEs and how these black holes shape their environments, we need to follow up on as many new events — and in as many wavelengths — as possible. So far, less than half of known TDEs were detected with radio signals.

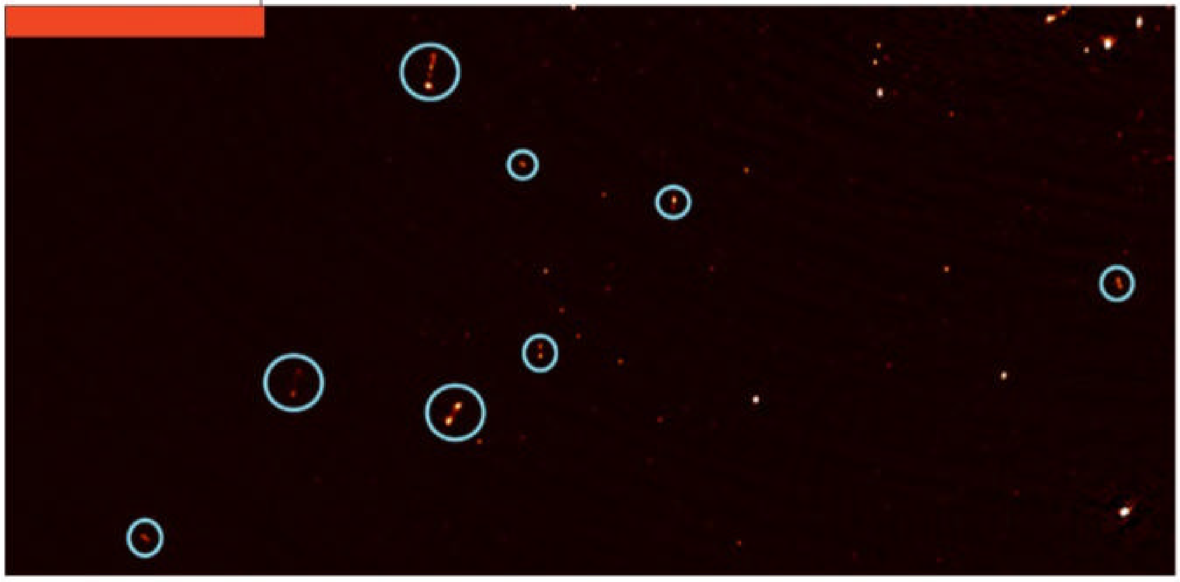
Alexander hopes to change that, and oversees a large VLA observing program (in which I also participate) to follow up on all new TDEs discovered in our local universe. The program has the right to "trigger" the VLA whenever a new TDE is discovered by another facility at another wavelength — that is, interrupt the schedule for time-pressing observations of our own to gather more data on nearby TDEs.

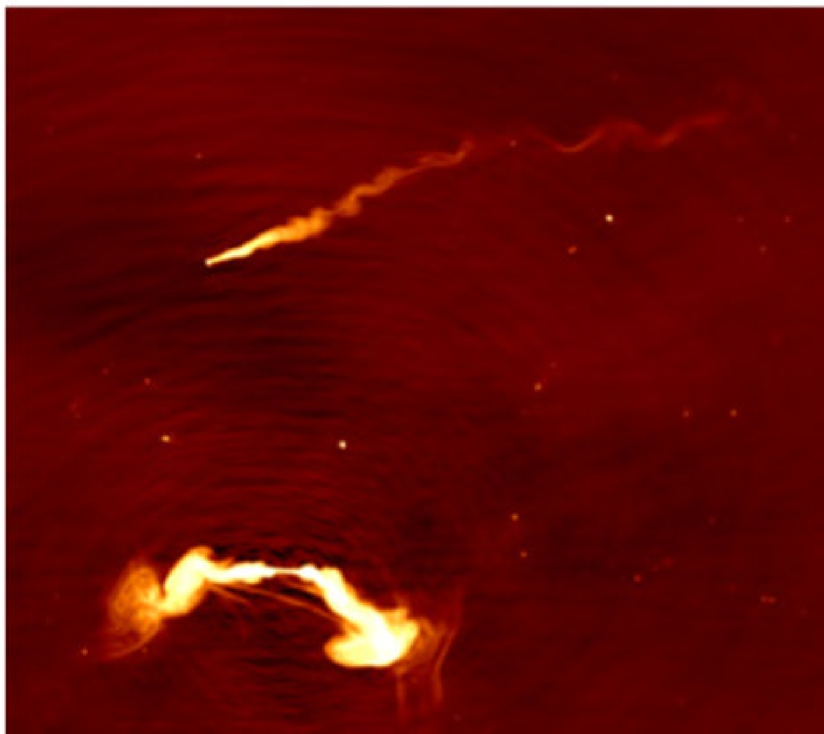
The detail and wide field of MeerKAT images make them unquestionably the prettiest I've seen.

Fresh eyes

However, the VLA can't do this work alone. From its location in New Mexico, it cannot see about a third of the southern sky. In fact, until the past few years, all but the brightest TDEs were unobservable in the southern skies because there was no facility as sensitive as the VLA with the right view.

Fortunately, this situation is changing rapidly, thanks to new

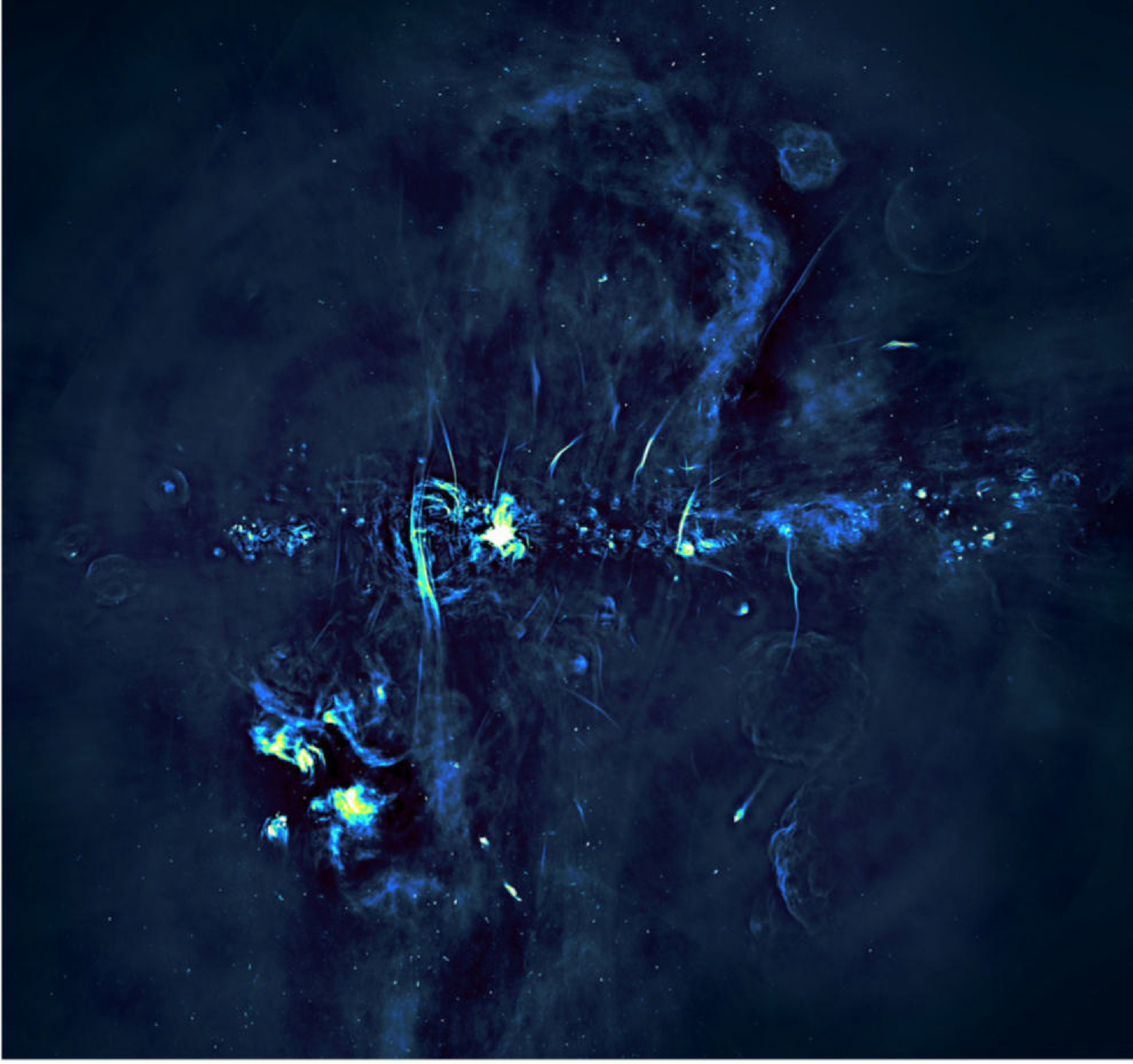




BELOW: Every circled object in this MeerKAT radio image is a supermassive black hole newly discovered by the telescope, firing relativistic jets into space. The image is a wide-field view spanning 1.78 square degrees.

BELOW RIGHT: Two bright radio galaxies launch relativistic jets in this MeerKAT radio image. The top galaxy is roughly 240 million light-years away; the bottom galaxy is about 130 million light-years distant.

BOTH: VETTE CENDES/SARAO



The region surrounding the Milky Way Galaxy's center has two enormous bubbles of hot gas being blown (upward and downward) in this MeerKAT image — evidence of the supermassive black hole's influence on its environment. Hot, thin magnetic filaments are also visible, where strands of the black hole's powerful magnetic field have heated and energized gas. SOUTH AFRICAN RADIO ASTRONOMY OBSERVATORY (SARAO)

telescopes like MeerKAT. Consisting of 64 antennas in South Africa's Karoo region, it's just as sensitive as the VLA. Eventually, it will become part of the Square Kilometer Array, which will be the most powerful radio telescope on Earth once completed in 2030, and comprise dishes scattered across South Africa and Australia.

MeerKAT saw first light in 2016 and, when the first call went out for non-South Africans to propose observations with MeerKAT, I jumped at the chance. My targets? A half-dozen TDEs, most of which had never been observed at radio wavelengths.

And that's how I found myself waking up one morning to a cellphone chime triggered by a radio telescope half a world away.

I've been lucky enough in my career to use a dozen different radio telescopes, but it was clear from the beginning that MeerKAT is different. I'm used to sources appearing as featureless blobs, but the detail and wide field of MeerKAT images make them unquestionably the prettiest I've seen — a large swath of sky with dozens of tiny galaxies floating in space. It is not unlike the Hubble Deep Field, but instead of the visible starlight Hubble sees, the galaxies in MeerKAT's radio images are powered by the supermassive black holes dwelling in their centers interacting with stray gas and dust. These encounters are steady, low-energy events that fuel most of the black holes in the universe.

Still, they're not what I'm after.

Finally, the MeerKAT image loads on my laptop. I pause to take in the whole thing — it feels like floating in space, if just for a moment — before zooming in to the center. And … there! A smudge of light at the center — the flare from a dying star whose remnants are being swallowed by a black hole, suspended alone in the middle of the cosmic ocean.

I smile and start planning the next steps of my analysis. The end of this star's journey means the beginning of my attempt to unravel its story, and there's a lot of work to do.

Yvette Cendes *is a postdoctoral fellow at the Center for Astrophysics | Harvard & Smithsonian. Follow her on Twitter* ***@whereisyvette****.*

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

Venus reaches greatest brilliancy early this month as an evening star. The planet reached the same magnitude in this 2018 shot as a morning star. ALAN DYER

DECEMBER 2021
Venus shines bright

December's early-evening sky offers a slew of planetary views, beginning with Venus, Saturn, and Jupiter — all on show soon after sunset. Capture the top features of the solar system in one evening by spotting the changing phase of Venus; the spectacular rings of Saturn; and the remarkably dynamic jovian atmosphere, its Great Red Spot, and Jupiter's four bright moons.

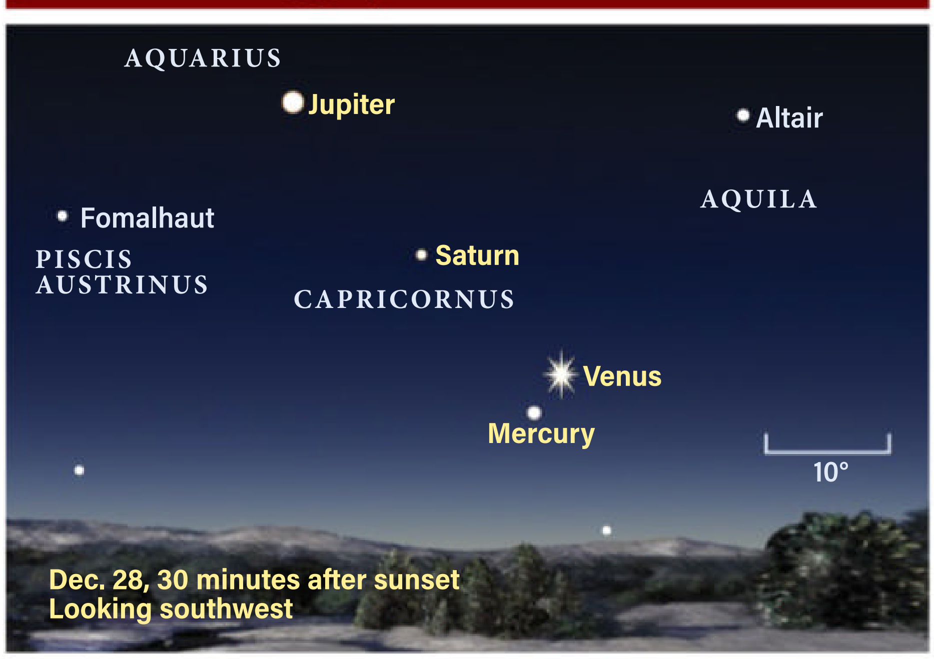
The first planet to appear after sunset is **Venus**, hanging low in the southwest. It reaches greatest brilliancy Dec. 4, when it shines at magnitude –4.9, easily piercing the bright twilight. This unmistakable brilliant jewel lies in eastern Sagittarius, featuring in all evening photographic compositions of the broad Milky Way.

A waxing crescent Moon, complete with earthshine, joins Venus Dec. 6, standing less than 3° away. As Venus slowly approaches the Capricornus border in mid-December, an interloper, Comet C/2021 A1 (Leonard), might be visible nearby if it reaches binocular brightness or better (magnitude 5). Observations of the comet Dec. 15 and 16 — after it appears in the evening sky — will give a good indication whether or not it will be easily visible.

On Dec. 17, Leonard stands 5° below Venus. Scan the region with binoculars for the fuzzy glow of the comet's coma. If the comet is brighter than predictions, it may just reach visibility to the unaided eye and even sport a short tail. The comet remains low in altitude for the next week, and like all comets, it will be best recorded in photographs.

The next day, Venus halts its easterly trek against the starry

Family portrait



By the end of December, four planets are readily visible in the evening sky: Mercury, Venus, Jupiter, and Saturn. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

VENUS will sit 5° above Comet C/2021 A1 (Leonard) on Dec. 17. The comet may just reach naked-eye brightness.

background just short of the Capricornus border and sinks back into twilight. Track Venus with a telescope to view its changing form. On Dec. 1, it shows a 28-percent-lit crescent spanning 39". The disk grows to 61" by Dec. 31, but shrinks to a mere 2 percent lit. This fast transformation occurs when Venus approaches inferior conjunction, which occurs early in 2022.

As Venus gets lower late in December, **Mercury** appears out of the Sun's glare. Try spotting the innermost planet Dec. 26, when it stands less than 6° below Venus. They appear closest on Dec. 28 — 4° apart — with Mercury shining at magnitude –0.8. By New Year's Eve, Mercury stands 1° higher than Venus. Check them out 45 minutes after local sunset.

Saturn joins Venus in the evening sky, shining a much fainter magnitude 0.6. They're 18° apart on Dec. 1, and are closest (14° apart) on Dec. 16. Saturn remains in Capricornus all month.

Grab your last telescopic view of Saturn and its rings for the year. The ringed planet is best during the first half of the month, when it remains above about 20° altitude for up to an hour after twilight ends. In late December, Saturn is too low for good views in a dark sky.

— Continued on page 38

RISING MOON | Nested craters

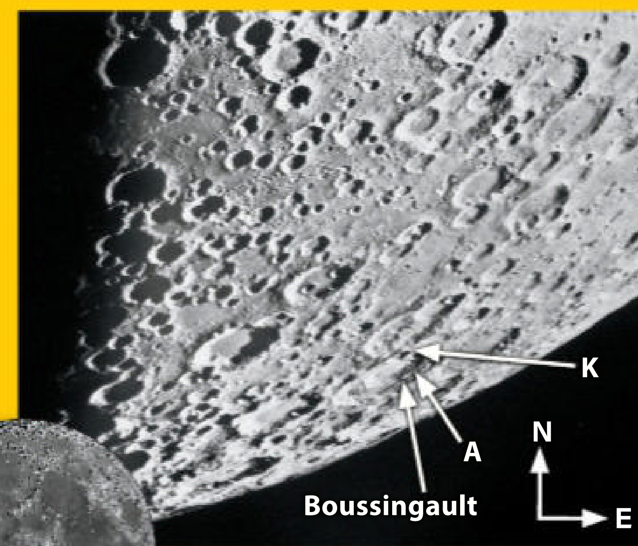
IT'S EASY TO FIND twin craters side by side or small circles inside much bigger ones — they're everywhere — but a Goldilocks bowl that's just right, nestled inside its parent crater? Boussingault in the far southeastern area of the Moon is the best fit. It is visible from the 7th through the 21st, as the Moon morphs from a fat crescent to a couple of nights past Full.

At first glance, you might think that this is a terraced feature, where the sides have slumped inward after the impact excavated a large hole. But after a few seconds, you will notice it definitely has a different appearance: Terraces don't have raised rims like the inner Boussingault A. Thanks to its far southern latitude, shadows hang around for many days, keeping the double nature distinct from the hundreds of other features in these crowded and rough lunar highlands. There is no central peak here — the original one was wiped out by the second impact, then lava pooled up from below to submerge it all.

Boussingault K, a younger, sharp-edged small crater, adorns the northern rim, clinching the positive identification of your target. An even smaller crater chips the southern flank. As much as the turbulence in our atmosphere permits, crank up the magnification and settle in for a while. Thanks to the shadows and our slanted view, the 3D appearance might give you a sense of sitting in low lunar orbit.

Compared to our view this month, the picture above shows us a bit beyond the limb. The slight nodding up and down of the Moon's face results from its orbit taking the Moon slightly above and below the imaginary level field of Earth's orbit around the Sun (the ecliptic). This particular image was taken with the Moon above the ecliptic, revealing more of its underside.

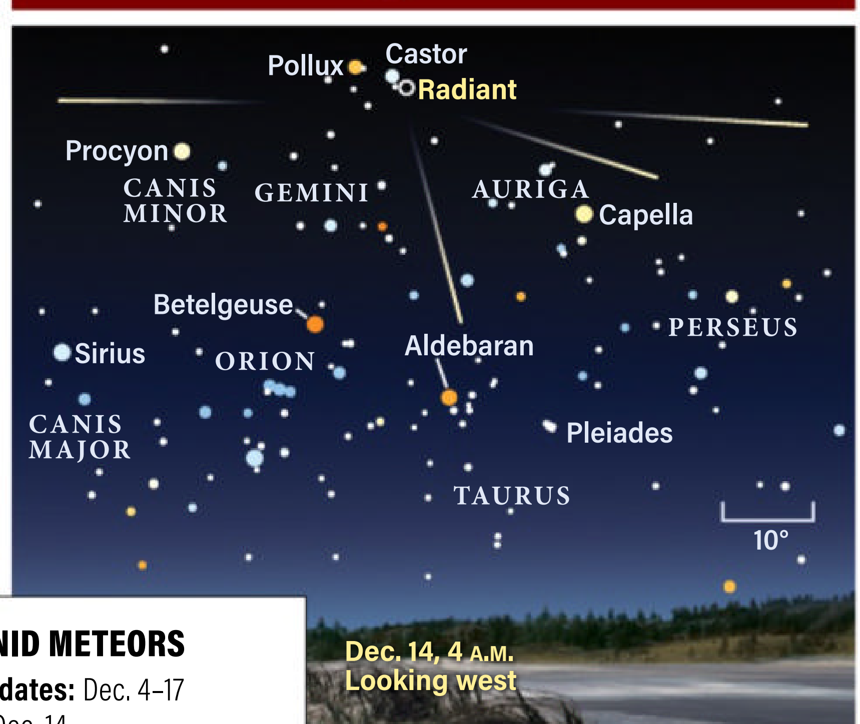
Boussingault



The crater Boussingault, named for a French botanist who lived in the 1800s, is our target this month. CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | One out of two

Geminid meteor shower



Your best bet to catch the most Geminid meteors is first waiting for the Moon to set on the morning the shower peaks.

GEMINID METEORS
Active dates: Dec. 4–17
Peak: Dec. 14
Moon at peak: Waxing gibbous
Maximum rate at peak: 150 meteors/hour

TWO MAJOR METEOR SHOWERS occur in December each year: the Geminids (Dec. 4–17, peaking on the 14th), and the Ursids (Dec. 17–26, peaking on the 22nd).

A waxing gibbous Moon lies in Pisces for the Geminids' peak, resulting in moonlight interfering until our satellite sets around 3 A.M. local time, offering a couple of hours of dark skies. The Geminids are one of the most favorable shower of the year, with close to 150 meteors per hour when Gemini is near the zenith. Although the Moon will affect this rate heavily, patient skywatchers can wait for the occasional bright event, which are usually spectacular.

The Ursids' peak is strongly affected by the Moon all night and this year the prospects are very poor for this shower.

STAR DOME

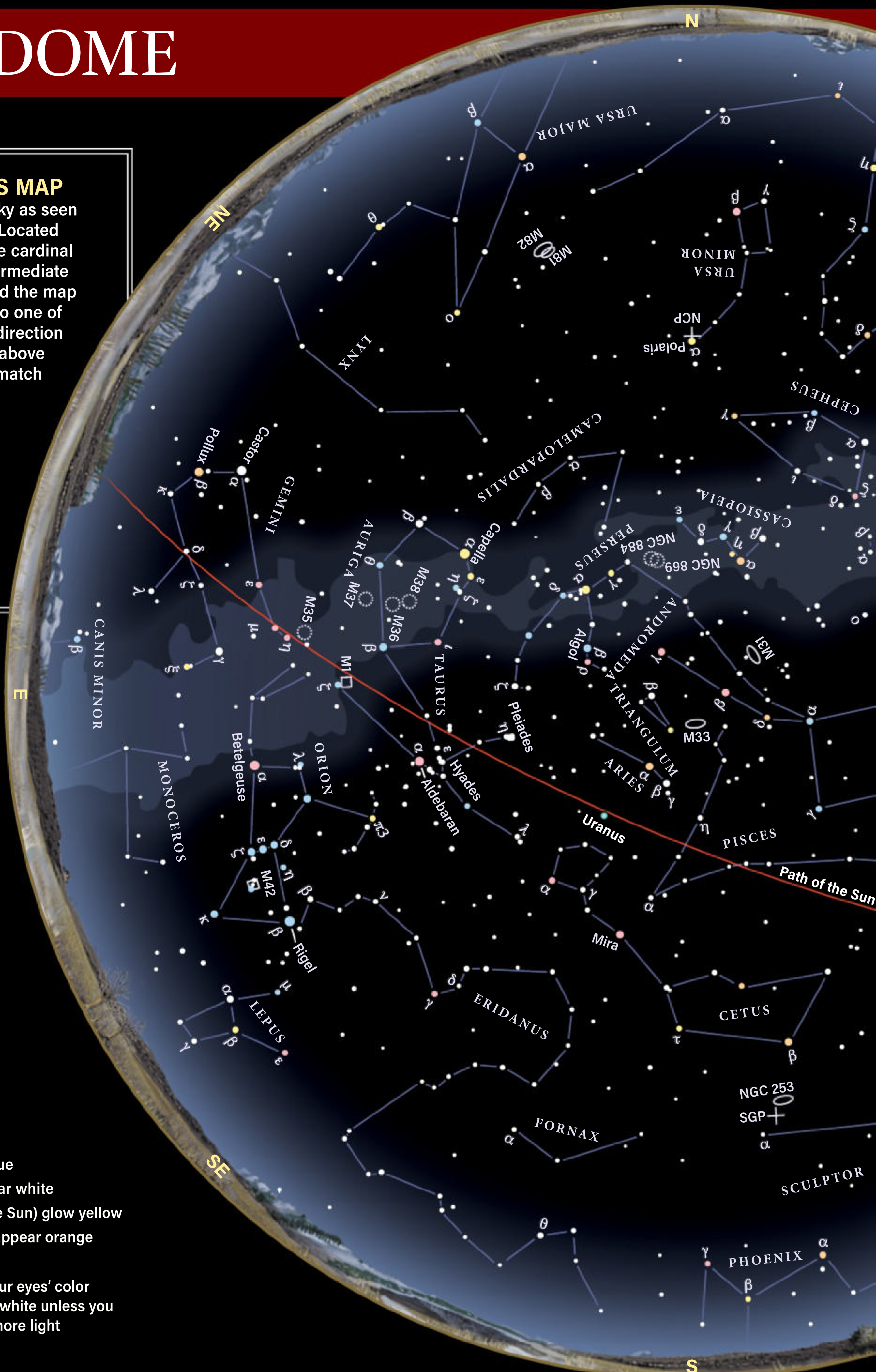
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. December 1
8 P.M. December 15
7 P.M. December 31

Planets are shown at midmonth



MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

DECEMBER 2021

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 Neptune is stationary, 5 P.M. EST

2 The Moon passes 0.7° north of Mars, 7 P.M. EST

4 New Moon occurs at 2:43 A.M. EST; total solar eclipse

The Moon is at perigee (221,702 miles from Earth), 5:04 A.M. EST

Venus is at greatest brilliancy (magnitude –4.9), 9 A.M. EST

6 The Moon passes 1.9° south of Venus, 8 P.M. EST

7 The Moon passes 4° south of Saturn, 9 P.M. EST

9 The Moon passes 4° south of Jupiter, 1 A.M. EST

10 The Moon passes 0.5° north of asteroid Pallas, 8 A.M. EST

Asteroid Nysa is at opposition, 9 A.M. EST

The Moon passes 4° south of Neptune, 8 P.M. EST

First Quarter Moon occurs at 8:36 P.M. EST

14 Geminid meteor shower peaks

15 The Moon passes 1.5° south of Uranus, 1 A.M. EST

17 The Moon is at apogee (252,475 miles from Earth), 9:15 P.M. EST

18 Venus is stationary, 6 A.M. EST

Full Moon occurs at 11:35 P.M. EST

21 Winter solstice occurs at 10:59 A.M. EST

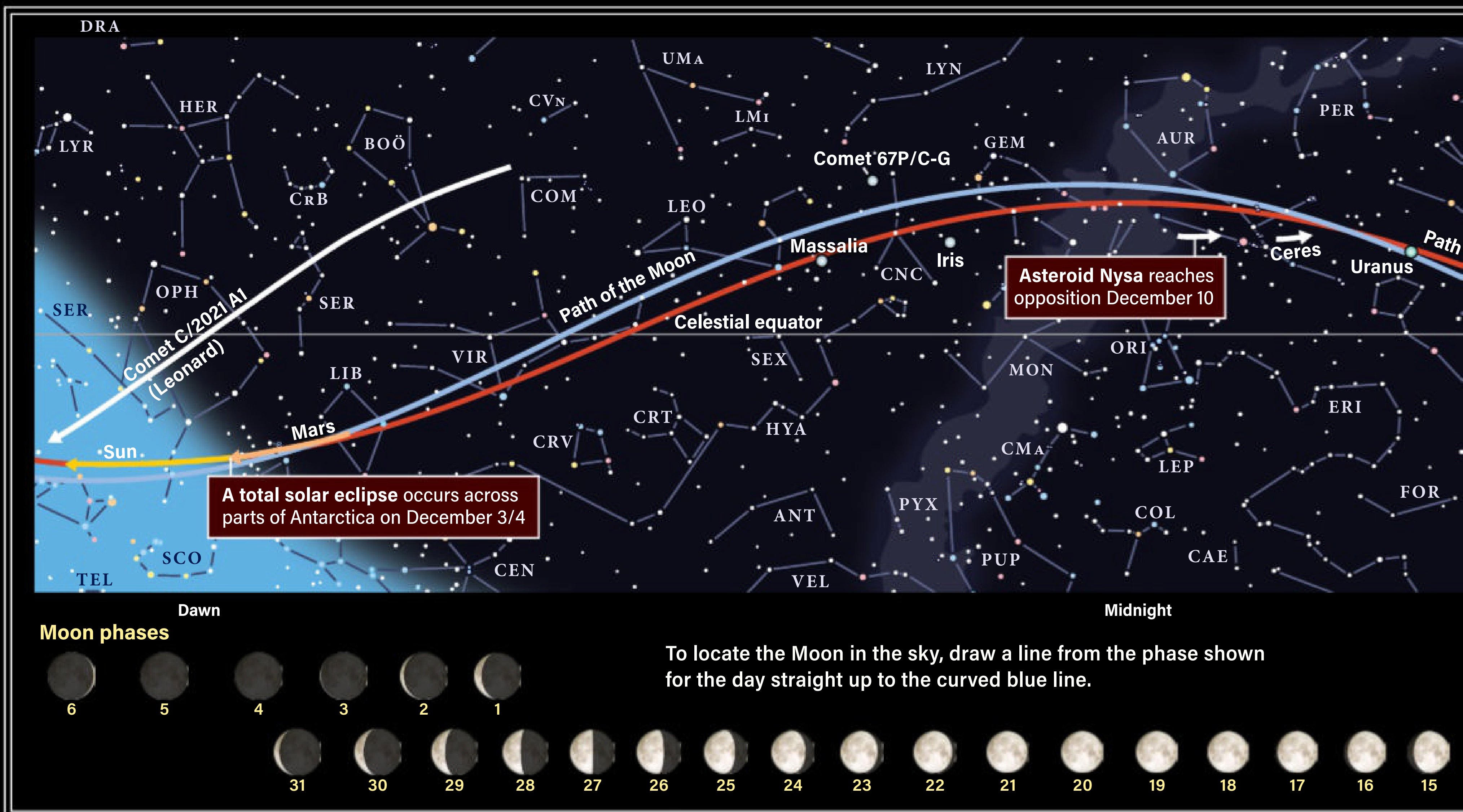
26 Mars passes 5° north of Antares, 1 P.M. EST

Last Quarter Moon occurs at 9:24 P.M. EST

28 Mercury passes 4° south of Venus, 8 P.M. EST

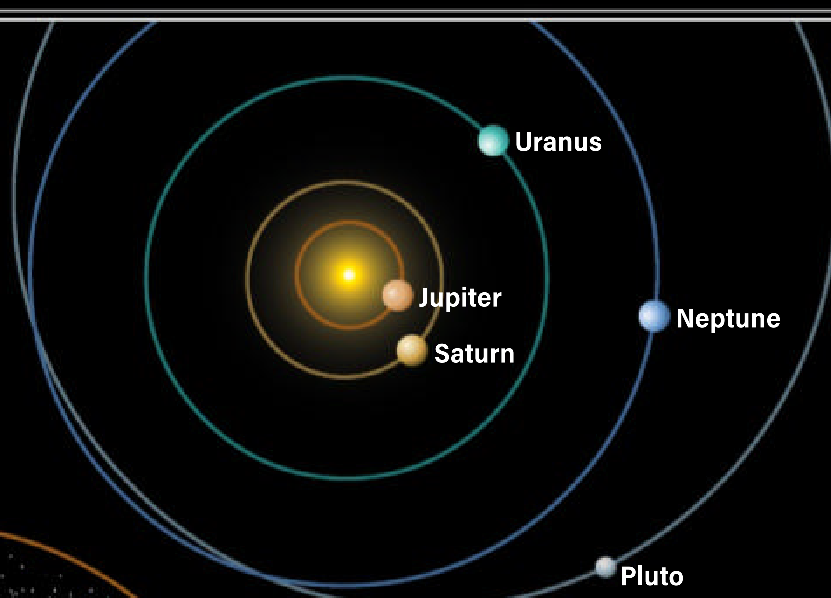
31 The Moon passes 0.9° south of Mars, 3 P.M. EST

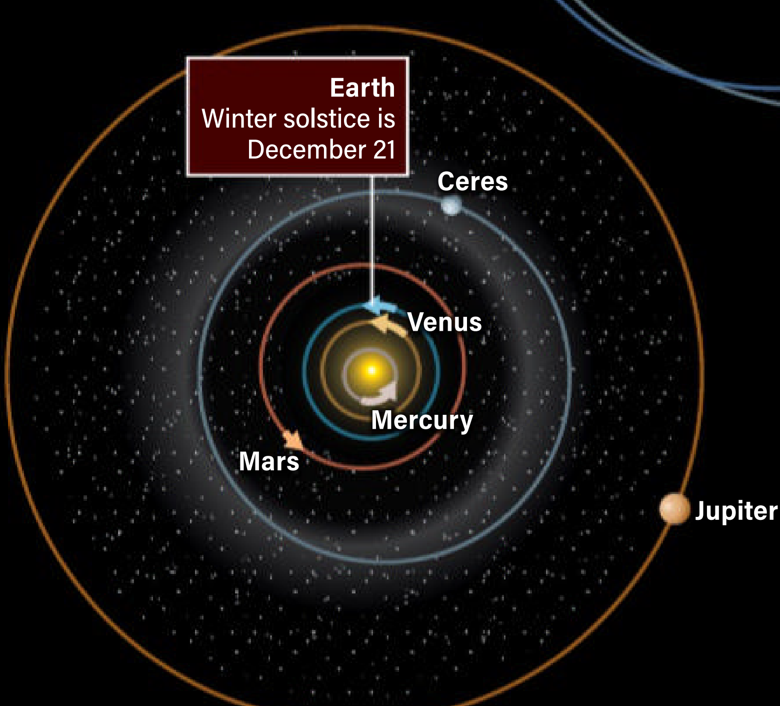
PATHS OF THE PLANETS

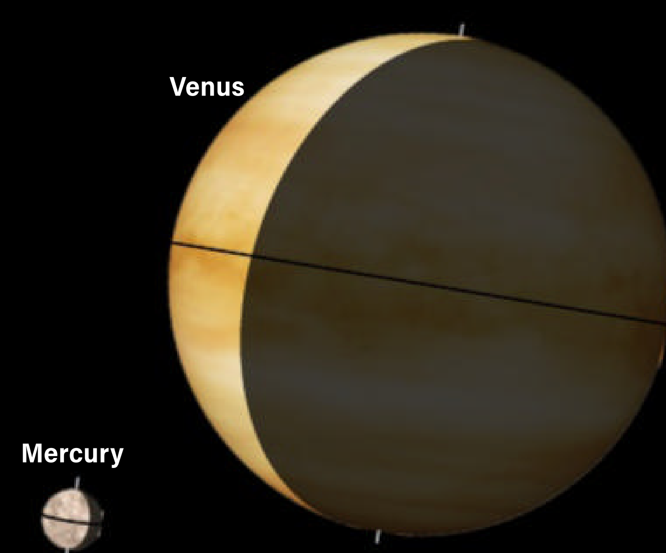


THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.



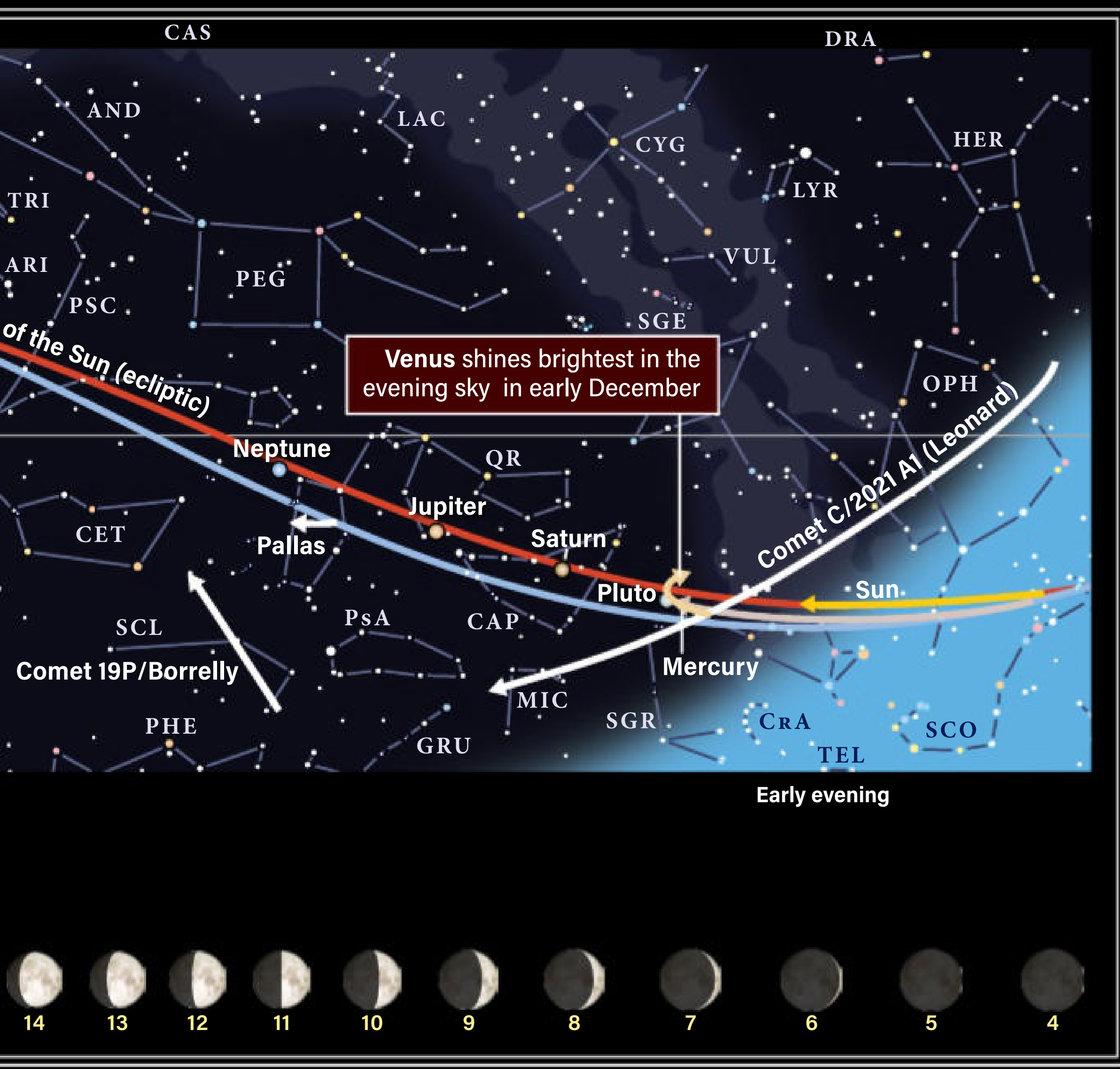




PLANETS	MERCURY	VENUS
Date	Dec. 31	Dec. 15
Magnitude	–0.8	–4.9
Angular size	5.8"	48.7"
Illumination	80%	16%
Distance (AU) from Earth	1.163	0.342
Distance (AU) from Sun	0.369	0.721
Right ascension (2000.0)	19h55.4m	19h52.0m
Declination (2000.0)	–22°44'	–22°02'

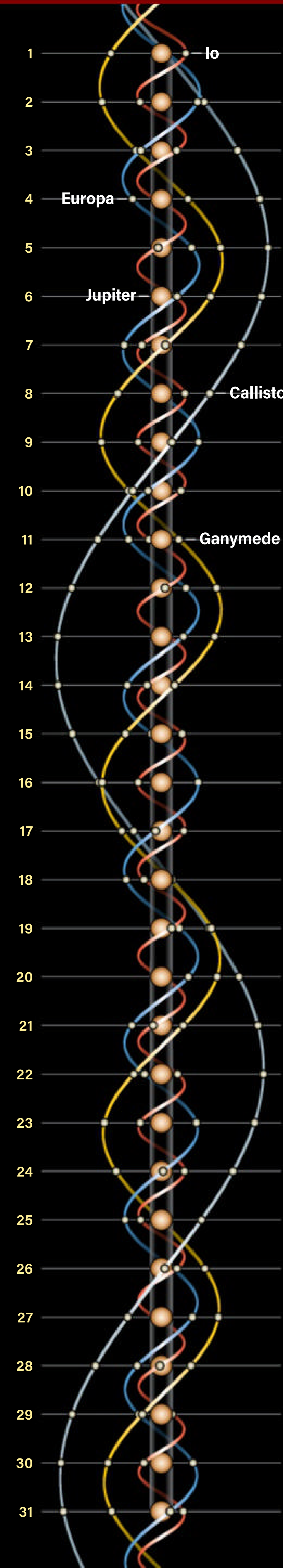
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

DECEMBER 2021



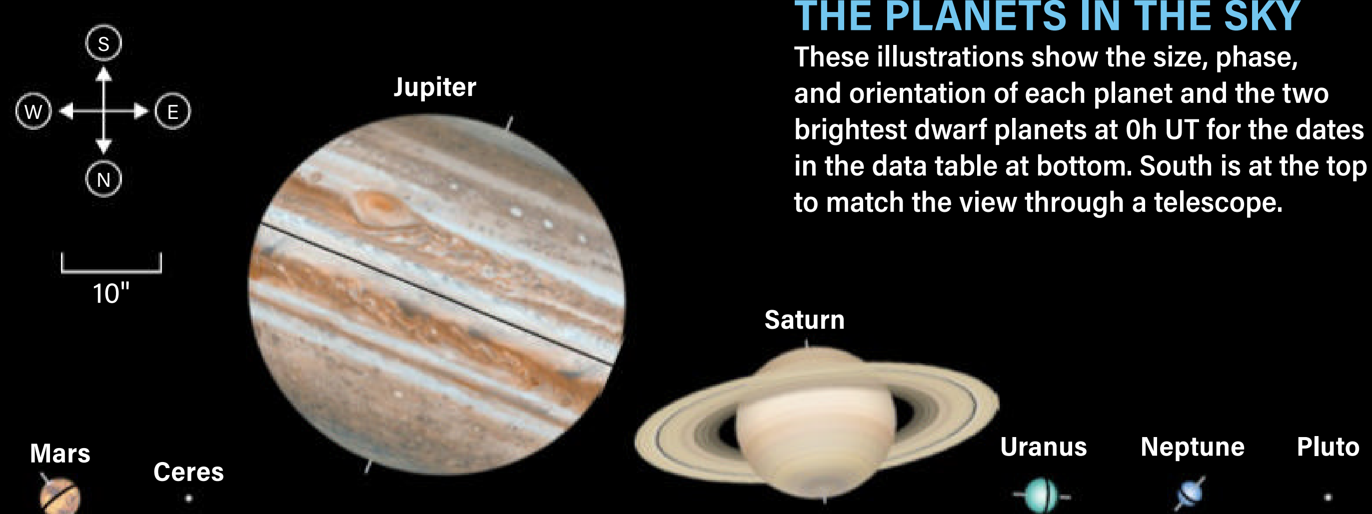
JUPITER'S MOONS

Dots display positions of Galilean satellites at 9 P.M. EST on the date shown. South is at the top to match the view through a telescope.



THE PLANETS IN THE SKY

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 15
1.6	7.4	−2.2	0.6	5.7	7.8	15.2
3.9"	0.7"	36.9"	15.7"	3.7"	2.3"	0.1"
99%	100%	99%	100%	100%	100%	100%
2.425	1.796	5.345	10.569	18.982	29.952	35.251
1.558	2.752	4.996	9.923	19.725	29.921	34.422
15h54.7m	3h57.6m	21h59.0m	20h50.2m	2h34.9m	23h25.6m	19h49.6m
−20°16'	17°07'	−13°25'	−18°34'	14°44'	−4°57'	−22°47'

SKY THIS MONTH — *Continued from page 33*

— Continued from page 33

Reappearing act

At 8:24 P.M. EST on the 26th, Europa is poised to emerge from Jupiter's large, dark shadow. Callisto, meanwhile, is closing in and will begin transiting the disk at 8:53 P.M. EST.

Saturn's disk spans 16"; the long axis of its rings span 35" and tilts 19° to our line of sight.

The easiest of Saturn's moons to spot is Titan, shining at magnitude 8. The fainter moons become more difficult to find in poor seeing conditions when the planet is at low altitude. Saturn sets shortly after 7 P.M. local time on Dec. 31, so be sure to catch it early.

Jupiter starts December in the eastern part of Capricornus, about 16.5° east of Saturn. It shines at magnitude –2.3, but quickly dims 0.1 magnitude and then crosses into Aquarius Dec. 14. The waxing Moon stands below Jupiter on Dec. 8, while Jupiter stands 10° west of the Moon on Dec. 9.

Jupiter's 37"-diameter disk looks great through a telescope — your best views will be as twilight descends and for the first hour or so after dark. By the end of December, Jupiter dips below 20° around 7 P.M. local time and sets by 9 P.M.

Check the configuration of its four Galilean moons — their relative positions change nightly. On Dec. 1, an occultation and eclipse reappearance occur close together. First, Callisto reappears from behind Jupiter at 9:13 P.M. EST, followed by Europa exiting Jupiter's shadow at 11:15 P.M. EST.

Watch Io disappear behind Jupiter Dec. 4 at 9:35 P.M. EST. The following night, both Io and its shadow travel across the face of Jupiter shortly after

> Comet C/2021 A1 (Leonard) skims within 2.6 million miles of Venus on Dec. 18.

WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (southwest)
Venus (southwest)
Jupiter (south)
Saturn (southwest)
Uranus (east)
Neptune (south)

MIDNIGHT
Uranus (west)

MORNING SKY
Mars (southeast)

COMET SEARCH | Best comet since NEOWISE

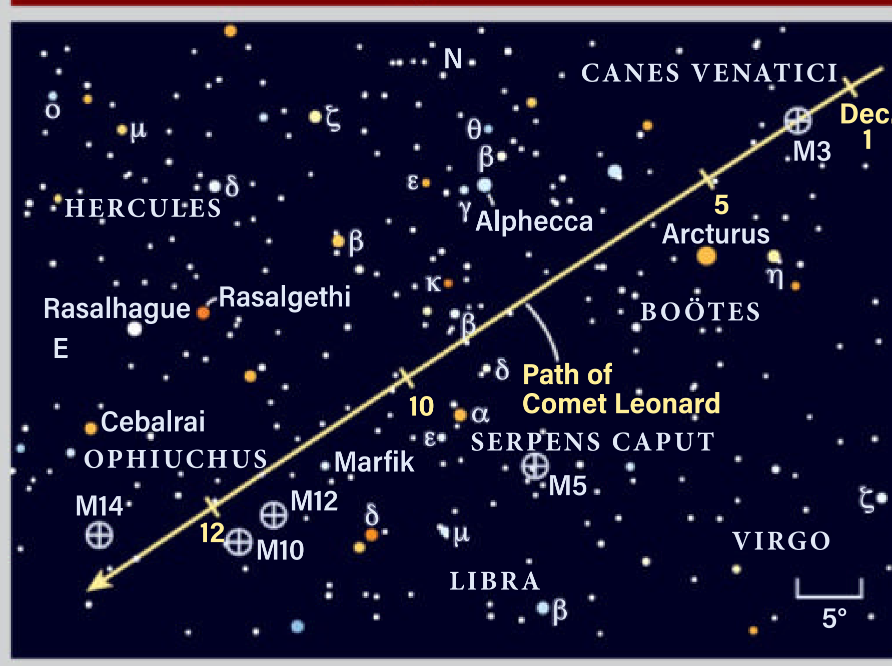
TAKE EVERY CHANCE you get to observe the brief appearance of Comet C/2021 A1 (Leonard). Visible to the unaided eye by the second week of December, it will rapidly fade to 8th magnitude by month's end. But what a show: An emerald blade shoots out on the 9th as its fan swishes in front of us!

The gas part of a comet's tail flows straight out, away from the Sun. Almost certainly it will be green, but blue — like C/2020 F3 (NEOWISE) — is possible. The dust component spreads out into a relatively flat fan, which becomes edge-on to our line of sight when Earth passes through the comet's orbital plane. The lightsaber likeness should be present for one night on either side of Dec. 9. It's not to be missed and worth a drive to darker skies.

Immediately after, the dust begins to blaze, peaking on the 14th. Dust forward-scatters light really well — best when the particles lie between us and the Sun — then fades night to night as the angles change. Don't be misled by thinking Gregory Leonard's comet will be best when it comes closest to the Sun (perihelion) in early January. More important is the increasing Earth-comet separation. Brightness drops by the square of the distance between two objects, meaning Leonard will fade to binocular brightness by the time we hit New Moon.

Beware of the confusing information on when to view Leonard. Technically, it is visible both after sunset and before sunrise in different parts of the sky. In a nutshell, here's when it's best: Up to Dec. 12, look southeast as dawn is breaking. From the 12th onward, switch to early evening and look low in the southwest. Find observing spots with as low a horizon and as minimal light pollution as possible.

Comet C/2021 A1 (Leonard)

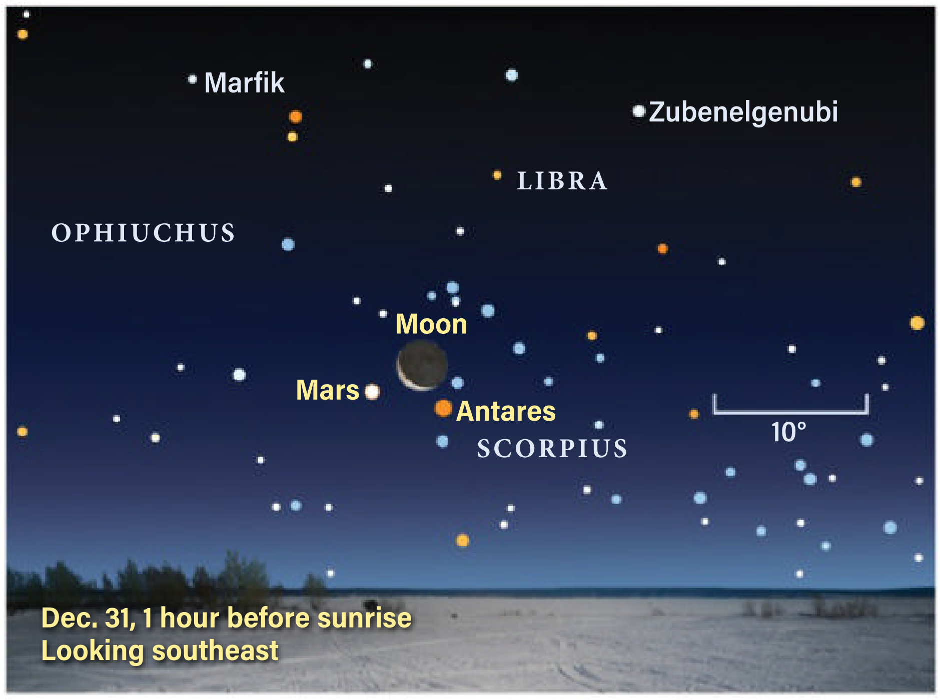


Early this month, Comet Leonard swipes past globular cluster M3 — compare their appearance! After midmonth, you'll want to switch from morning to evening viewing. Our friends south of the equator see only the second half of the performance.

Note that our illustration shows the comet's progress only through Dec. 12. Visit www.Astronomy.com/skythisweek later this month for charts and viewing tips through the latter half of December.

Other visible comets this month include, in order of brightness, 67P/Churyumov-Gerasimenko, 9P/Borrelly, and C/2019 L3 (ATLAS).

Red-letter day



Mars and the Moon give 2021 a grand send-off in Scorpius, where they hang near the famously red-hued star Antares.

darkness falls. Io's transit ends at 9:14 P.M. EST, followed by its shadow 75 minutes later. Two days later, Ganymede, Jupiter's largest moon, transits on Dec. 7 beginning at 9:03 P.M. EST. The event continues for more than 3 hours.

Neptune is a binocular object shining at magnitude 7.8 most of the month and located in Aquarius the Water-bearer. It stands high in the southern sky Dec. 1 and remains visible all evening until it drops very low after 11 P.M. local time. The distant planet lies 3° northeast of the 4th-magnitude star Phi (ϕ) Aquarii on Dec. 1. That night, Neptune is at its stationary point; it barely moves all month. Neptune stands 4.5° north of a First Quarter Moon on Dec. 10.

At the ice giant's huge distance of nearly 30 astronomical units (where 1 astronomical unit or AU is the average Earth-Sun distance) from us, its disk spans only 2" through a telescope. Use high magnification on a steady night of seeing to reveal its bluish-green disk.

Uranus stands high in the sky against the backdrop of Aries the Ram every evening and sets in the early morning hours. It lies about 11° southeast of Hamal, the brightest star in Aries. Uranus shines at magnitude 5.7, an easy object for binoculars once you find the right field of view. The ice giant stands about 3° northeast of the gibbous Moon on Dec. 14.

December is a great time to view Uranus with a telescope, given its high altitude after dark. Uranus spans 4" with a distinctive greenish-blue hue. At a distance of 1.7 billion miles (19 AU), it's a wonder to behold.

Mars reappears in the morning sky in Libra and crosses into Scorpius midmonth, then moves into Ophiuchus Dec. 25. That morning, it shines at magnitude 1.6 less than 5° north of its noted rival, Antares, which is the brighter of the two (magnitude 1.1). Mars rises nearly two hours before the Sun, so look for it low in the southeast as twilight begins. On the last morning of the year, a waning crescent Moon stands within 4° of Mars and Antares — a beautiful sight in the predawn sky.

The winter solstice occurs Dec. 21 at 11 A.M. EST.

A total solar eclipse takes place Dec. 4 across Earth's southern pole. The longest duration of totality is 1 minute 54 seconds. A number of cruises are slated to travel to locations along the eclipse track. The eclipse begins at sunrise in the South Atlantic Ocean and crosses Coronation Island, the largest of the South Orkney Islands. The eclipse path then crosses the Weddell Sea and makes landfall again on the Ronne Ice Shelf and Berkner Island. A small partial eclipse of the Sun will be visible across southern Africa, Tasmania, and southern Australia.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Wichita, Kansas.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

LOCATING ASTEROIDS

Ceres from the city

WHILE DWARF PLANET 1 CERES quickly crossed the star-studded face of Taurus the Bull last month, it now begins a stroll into the populated Milky Way. The space rock is perfect for binoculars from the suburbs, having just peaked at magnitude 7 on Nov. 29 during opposition.

As bright as Ceres is, it can almost hide in the crowd. Scan the chart below or print out a larger-scale copy to mark when you saw it. Use the 6th-magnitude stars as your pattern anchor to positively identify the right dot.

It was back in 1801 that Giuseppe Piazzi was comparing telescope fields with star charts and picked out this undiscovered planet. Like him, wait a night or two to confirm its motion against the background. At month's end, Ceres has faded a whole magnitude, but is easier to spot in the sparser starfield.

Earth now pulls ahead on its inside track, lapping Ceres in 2023. The paths are not round, however, which will bring the main-belt asteroid slightly closer to Earth than it's been since 2005. These brighter oppositions come in cycles of nine and 14 years.

Lost in the crowd

To track Ceres through this crowded region, choose several stars as anchor points to catch the bright spot that moves.

Double down on DOUBLE STARS

ABOVE: The Big Dipper in Ursa Major houses a famous double star that ancient Arabic texts refer to as a visual test. Just at the kink in the Dipper's handle is bright Mizar, with dimmer Alcor 12' to its east-northeast (upper left in this image). ALAN DYER

LEFT: This meticulously hand-drawn diagram from Edward Crossley's *A Handbook of Double Stars* shows the orbits of Castor A and B. RAYMOND SHUBINSKI

Roughly half the sky's stars have a partner. Here are some of the most famous, colorful, and compelling pairs.

BY RAYMOND SHUBINSKI

VIEWING DOUBLE STARS is a popular activity at star parties. The presenter will usually point out Mizar and its dimmer companion, Alcor, in the bend of the Big Dipper's handle; or, in summer, telescopes are often turned to Albireo in Cygnus, to everyone's delight.

But double stars are often neglected by today's serious amateur observers, who are more interested in deep-sky objects. It's a shame, because not only are double stars beautiful, but they are also a challenge by which to measure the skill of the observer and the quality of their telescope. Double stars were once the focus of both professional and amateur observers alike, and they have played an important role in our understanding of gravity and of the galaxy in which we live.

Seeing double

Mizar and Alcor have long been a test for good eyesight. Called the horse and rider, these stars (and hence the ability to separate them) are even referred to early Arabic texts as "the test." But skywatchers had no idea that they were seeing just a chance alignment. Mizar and Alcor now appear to be part of a group of stars moving together through the galaxy, but they are not a true binary system bound by gravity. They are instead called a common proper motion pair.

Less than 10 years after Galileo turned his telescope to the sky, his friend Benedetto Castelli discovered that Mizar has a nearby companion — Mizar B — of almost equal brightness. Mizar is easy to split in a small telescope. Castelli also noted the nearby companion of Beta (β) Scorpii, another favorite for small telescopes. In the mid-17th century, the English scientist Robert Hooke split Gamma (γ) Arietis in the Ram. Yet none of these observers could determine whether the stars were physically related.

In 1849, Sir John Herschel wrote in his book *Outlines of Astronomy*, "Many of the stars, when examined with a telescope, are found to be double. … This might be attributed to accidental proximity, did it occur only in a few instances." He goes on to write that "the frequency of this companionship [and] the extreme closeness," means many must be physically related.

Anyone who has swept a star-filled sky with binoculars or a small telescope has seen the profusion of what appear to be closely related stars. But the true relationship of double stars is more complex than Herschel's straightforward statement. If you have a modest backyard telescope, you can follow the trail that led to our understanding of the true nature of double stars.

Gamma Virginis (Porrima)

A sketch made with a 6-inch f/8 Newtonian scope resolves the two stars that make up Porrima in Virgo the Maiden. JEREMY PEREZ

PERFECT EYESIGHT NOT REQUIRED

Presenters at star parties often say that in ancient times, the ability to see both Mizar and Alcor would qualify you for the Roman army. I have searched Roman literature by Cicero, Pliny the Elder, Seneca, and, most importantly, *De Re Militari* by Vegetius. There is no mention of any such test of eyesight either for foot soldiers or archers. Early Arabic literature does mention Alcor as a test for visual acuity, but as far as the Romans were concerned, if you could pick up a sword and shield, they signed you up for active duty. *—R.S.*

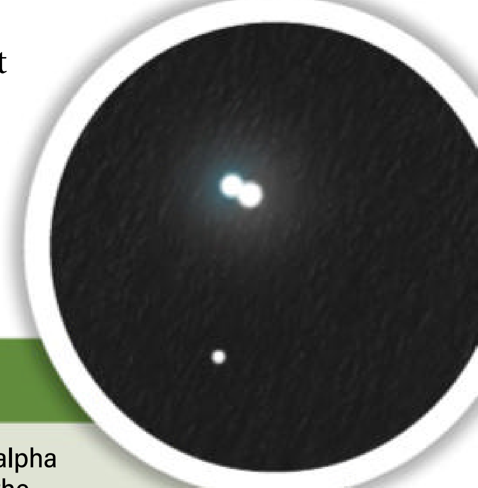
Follow the stars

Let's start in the constellation Cygnus. The Swan is full of wonderful objects, including two fascinating double stars. One is **61 Cygni**, an easy target for a small telescope. To find it, draw a line from the tail of the Swan, Deneb, to the tip of its right wing, Zeta (ζ) Cygni. 61 Cygni lies about halfway between these two stars. You will need a dark sky to see the primary, at magnitude 5.2, with the unaided eye. A good pair of binoculars will split the two widely separated stars. The companion shines at about 6th magnitude.

In 1804, the astronomer priest Giuseppe Piazzi showed, based on repeated observations, that 61 Cygni was moving noticeably against the background of the other stars in the Swan. Because of its high proper motion, he christened it the Flying Star. Three decades later, Friedrich Bessel reasoned that 61 Cygni must be relatively close to Earth. After years of observations, he was able to make the first measurement of stellar parallax, using the double star's motion against the more distant, stationary background to determine it is only 10.4 light-years away. Modern observations place it just 1 light-year farther.

Next, let's move on to Virgo. The Maiden looks like a giant letter Y. **Gamma Virginis**, also known as Porrima, is the star at the joint of this Y. On a spring night, turn a telescope on Gamma; the two stars of this system are almost equally bright at magnitude 3.65 and 3.56. They look like two tiny headlights in space.

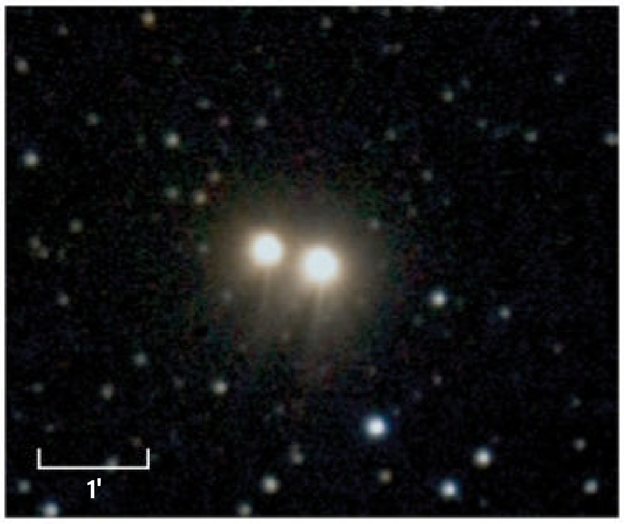
This particular double star helped confirm the universal nature of Newton's theory of gravity. Early 19th-century astronomers, including Herschel, spent years refining their observations of this fascinating star system. The two stars have an orbital period of almost 169 years. At their greatest angular separation, they are nearly 6" apart. At their closest, they become difficult to split in a large-aperture telescope. This disappearing act occurred in 1836, and by charting

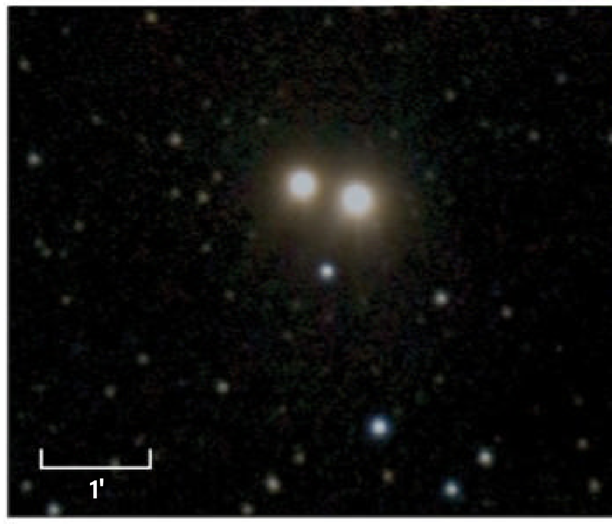


Castor

Castor is Gemini's alpha star and garnered the attention of both William and John Herschel. This sketch shows the system's two brightest stars through an 8-inch f/6 Newtonian at 240x. JEREMY PEREZ

Mizar (right) is itself a binary star, with its two components 14" apart. Alcor, visible at left, is not in a system with Mizar, although the two share the same proper motion. GIUSEPPE DONATIELLO





61 Cygni

61 Cygni is known as the Flying Star for its rapid motion against the background stars. These images, taken eight years apart, show the pair's displacement over time. INDIVIDUSOBSERVANIS/WIKIMEDIA COMMONS

the stars' motions, astronomers proved they were orbiting each other according to Newton's law of gravity. This, in turn, showed gravity not only works in our solar system with the Sun, the Moon, the planets, and other small bodies, but also in the depths of interstellar space!

The stars again came closest in 2005. Currently, they are approaching 3" in separation, making them fairly easy to split with a small telescope. As a bonus for observers, Porrima lies less than 3° above the ecliptic and is occasionally occulted by the Moon.

The winter sky gleams with bright jewels, and one of the best is **Castor** in Gemini the Twins. At magnitude 1.9, Castor is the 25th-brightest star in the sky. It is also a fascinating multiple-star system. Through a modest-sized telescope, Castor is relatively easy to split into two stars, with the companion shining at magnitude 2.97 about 5" from the primary.

Albireo

One of the sky's most stunning double stars is Albireo, whose components are brilliant sapphire and yellow. ALAN DYER

Sir William Herschel was the first astronomer to systematically study double stars. When he started his work in 1800, he "resolved to examine every star in the heavens with the utmost attention" — a monumental challenge for any observer. After several years observing Castor and its companion, Herschel was convinced the pair was a true binary star system and not a chance alignment.

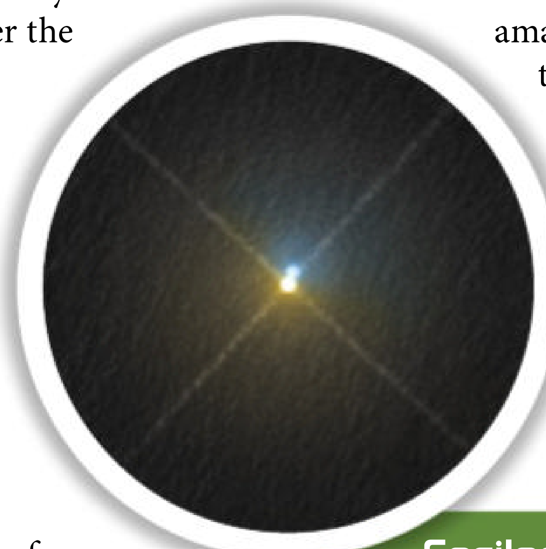
This was later confirmed by John Herschel, William's son. John continued his father's studies of Castor, and gathered observations taken by other astronomers over the previous 100 years. These allowed him to produce detailed elements of the stars' orbits, making this the first confirmed binary. We now know that Castor is even more complex than the Herschels could have imagined, with a total of six stars locked in mutual orbits.

Color vision

The night sky is punctuated with stars that present both vivid and subtle hues. It's easier to see these incredible colors on display in double stars because their proximity makes them easy to compare. During the 19th century, avid double-star observers reported an amazing range of colors among paired stars. Astronomer Joel Dorman Steele wrote, "Every tint that blooms in the flowers of summer, flames out in the stars at night."

Bear in mind, though, that humans see the full range of color best in bright sunlight. The ability decreases as the light level drops. In the dark, we are more sensitive to blues and greens. This certainly affects the way we see color in stars through a telescope.

Gleaming yellow and amber in the head of Cygnus is the constellation's other famous pair: **Albireo**, the crown jewel of double stars. Turn a small telescope on this star and it will resolve into a golden primary (Albireo A) and a brilliant sapphire blue companion (Albireo B). Some observers see a hint of green in the fainter star. This may be an effect of the contrast between the two stars, whose amazing colors arise from their physical properties. Albireo A is a giant more than 14 times the mass of the Sun, producing light in the yellow-orange part of the spectrum. Its companion is younger and only



Epsilon Boötis (Izar)

Izar in Boötes shows off its colorful components in this 2012 sketch made through a 6-inch 6/8 Newtonian scope. JEREMY PEREZ

Gamma Delphini

ABOVE: Although this wide-field view of Delphinus doesn't split Gamma (upper left), the star does appear slightly greenish. ALAN DYER

LEFT: This sketch, made with a 6-inch f/8 Newtonian telescope at 240x magnification, splits Gamma Delphini into two stars. JEREMY PEREZ

SEEING CLEARLY

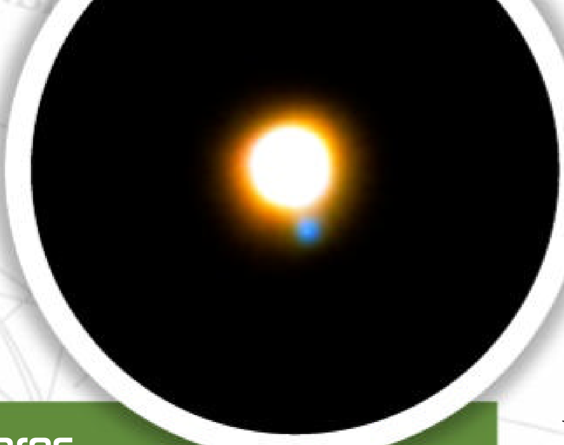
Throughout the 19th century and well into the 20th, both professional and amateur astronomers preferred refracting telescopes. Refractors offer a clear aperture free of the distortion and diffraction caused by the secondary mirror in reflecting telescopes. But two drawbacks of early refractors were their long focal length and their chromatic aberration, which cause poor images and color distortion, respectively. The development of achromatic and apochromatic lens systems has eliminated these issues. I currently observe double stars with both a 6-inch Celestron refractor and an 8-inch Celestron NexStar Evolution HD reflector. Both scopes provide excellent images, as will many others. Even a good pair of binoculars can provide enjoyable viewing of wide double stars. *—R.S.*

about four times the mass of our Sun; it shines with intensely blue-white light.

Astronomers long wondered whether these two stars were physically related. In the last few years, the European Space Agency's Gaia spacecraft has provided data suggesting this is an optical double, also known as a line-of-sight double. Regardless, the close visual effect is spectacular and Albireo is always a favorite object for viewing.

But perhaps aiming to take Albireo's spot is **Izar** (Epsilon [ε] Boötis), also known as *Pulcherrima*, Latin for "the most beautiful." That name was bestowed by Friedrich Georg Wilhelm von Struve, who split the star into two colorful companions using the Great Dorpat Refractor in Estonia. He said the primary was gold and the secondary an appealing blue. Other observers claim the stars look yellow and green, respectively. Epsilon can be difficult to separate with a small telescope but is well worth the effort.

Yet another crown jewel of the sky, **Gamma Delphini** is located in the constellation Delphinus' Job's Coffin asterism. An easy double to split, observers describe it as having unusual colors.



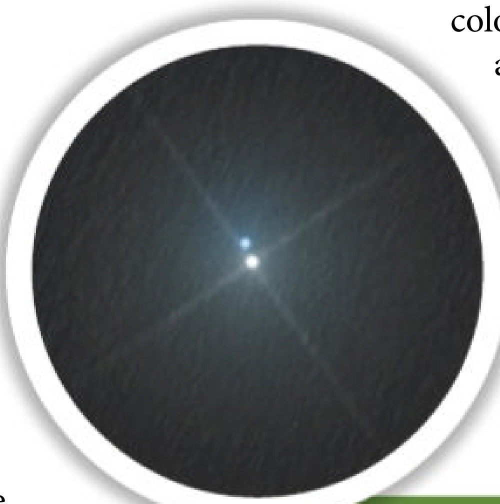
Antares

This highly magnified shot shows Antares' much smaller close companion, Antares B. GIUSEPPE DONATIELLO

Nineteenth-century observer Admiral William Henry Smyth called it a "beautiful double star" and said the two stars appear yellow and light emerald. Others have said they're orange and lime. What do you see?

One of the most glorious stars in the sky is **Antares**, the heart of the Scorpion. The name means "rival of Mars." And anyone who has scanned the summer sky knows that Antares has a distinct red hue. At a distance of 550 light-years, this star is a nearby red supergiant.

In 1844, Scottish astronomer James W. Grant observed a companion star near Antares. The secondary star was seen again in 1846 by American astronomer Ormsby M. Mitchel. The two stars are separated by 2.5" and their colors have been described as fiery red and green or blue. The prolific English astronomer the Rev. Thomas W. Webb said that the companion appeared "yellow, with flashes of deep crimson alternating with a less proportion of fine green." Antares is so bright that the fainter star can be overwhelmed by its glare, making this delightful double star a challenge to split, depending on the telescope and sky conditions.

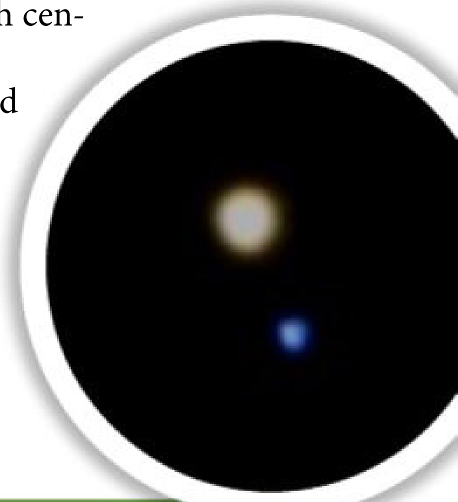


Beta Scorpii (Acrab)

This sketch of Beta Scorpii, made with an 8-inch f/5.9 Newtonian telescope, shows the white primary accompanied by a secondary that appeared blue to the observer. JEREMY PEREZ

Also in Scorpius, **Acrab** (Beta Scorpii) at the root of the Scorpion's uppermost claw is yet another colored double star. With a separation of more than 13", this system resolves into two stars at relatively low power. Beta appears truly white, while the second star has been called lilac or green. The discrepancy may be due to contrast between the two stars. Like Porrima, Acrab lies on the ecliptic and is occasionally occulted by the Moon.

Our final destination is the left foot of the Princess Andromeda, which holds the delightful double star **Almach** (Gamma Andromedae). First split in the late 18th century, the two stars have been described as orange and emerald green (like Gamma Delphini). Others have seen gold and indigo blue. This contrasting pair provides yet another challenge for color perception.



Gamma Andromedae (Almach)

Almach, located in the foot of Andromeda, has a small companion that may appear either green or blue, depending on your color perception. NVN271/WIKIMEDIA COMMONS

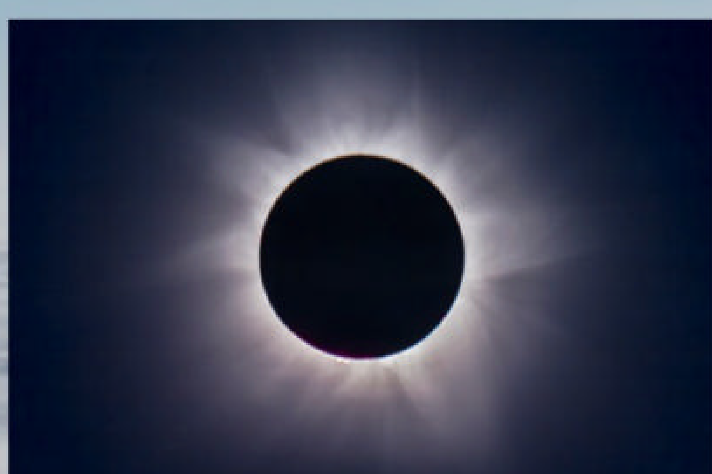
See for yourself

Observing double stars is a rewarding experience. They give us the opportunity to challenge our equipment, our sky conditions, and, most of all, our own observing skills. If you have the patience to watch stars like 61 Cygni over the course of many years, you'll see that the sky isn't static, but dynamic and alive. And ultimately, the challenge of visually observing double stars gives a sense of connection with the cosmos that no photograph can possibly convey.

Raymond Shubinski *has observed all of these double stars and more. He also enjoys comparing his observations with those of bygone astronomers.*

A TOTAL SOLAR ECLIPSE OVER ANTARCTICA

To chase down the Moon's shadow this month, you'll need to put yourself on ice. **BY MICHAEL E. BAKICH**



LEFT: A total solar eclipse is a not-to-be-missed event that will leave you breathless. This processed image is a single frame from an HD video shot through a 106mm refractor at f/5.8 during the Nov. 14, 2012, eclipse over Lakeland Downs, Queensland, Australia. RIGHT: These brightly colored clam tents serve as guests' Antarctic home away from home at Union Glacier Camp.
ALAN DYER; CHRISTIAN IVERSEN STYVE/ALE

ON DEC. 4, a three-way celestial tango will once again occur as the Sun and the Moon line up with Earth to produce the greatest of nature's spectacles: a total solar eclipse. And while many eclipses occur in faraway places, this one takes the cake. The darkest part of the Moon's shadow during December's eclipse will touch only the continent of Antarctica. So, pack your camera, your eclipse glasses, and your winter survival gear if you're going to chase this event.

What's going on

Total solar eclipses occur more often than total lunar ones, but more people have seen a total lunar eclipse (although the number of observed solar eclipses has been rising in recent years). The reason for the disparity is simple. During a lunar eclipse, anyone on the nightside of our planet under a clear sky can see the Moon passing through Earth's shadow. Even at the Moon's distance of about 238,000 miles (383,000 kilometers), that shadow is much larger than Luna. If the Moon passes through the center of our planet's shadow, totality can last as long as 106 minutes — though it's usually less because the Moon passes either above or below the shadow's center.

On the other hand, the Moon's diameter is a quarter of our planet's, so its shadow barely reaches Earth's surface to create solar eclipses. If you're beneath the lighter, outer region of that shadow — called the penumbra — you'll see a partial solar eclipse. As long as you're wearing your eclipse glasses, a partial is nothing to scoff at, but there won't really be any noticeable dimming of the Sun's brilliance. The lucky individuals under the dark inner shadow — the umbra — will witness the daytime twilight of a total solar eclipse. Making that event even more dramatic is the fact that it doesn't last long. Solar totality lasts a maximum of 7 minutes 29 seconds.

Two travelers observe the early-morning Sun as it hangs over the mountains near Antarctic Logistics & Expeditions' Union Glacier Camp. This site will receive 47 seconds of totality on Dec. 4. CHRISTOPHER MICHEL/ALE

Unfortunately, an eclipse sporting that duration won't occur until July 16, 2186. This December, the maximum duration of totality is 1 minute 54 seconds.

The path

The Moon's penumbra first touches Earth at 12:29:11 A.M. EST (5h29m11s UT) and leaves its surface at 4:37:24 A.M. EST. The total phase of the eclipse begins at 2:00:01 A.M. EST some 217 miles (350 km) east of the Falkland Islands, at longitude 51°10'46" West and latitude 53°06'32" South.

The umbra remains in contact with Earth's surface for 1 hour 6 minutes 28 seconds, until 3:06:29 A.M. EST. Finally, it vanishes 280 miles (450 km) north of the Antarctic coast at longitude 138°43'44" West and latitude 67°04'07" South. The total path length is 3,708 miles (5,968 km), which is relatively short. By comparison, the upcoming 2024 total solar eclipse that passes through the U.S. will sport a path length of 9,190 miles (14,790 km).

For this month's eclipse, the Moon's diameter will be 33'29", while the Sun's apparent span will be 32'27". Astronomers call the ratio of the diameters of the Moon and the Sun an eclipse's magnitude. The magnitude of this eclipse is 1.0367. Put another way, the Moon will appear 3.67 percent larger than the Sun. Greatest eclipse occurs at 2:33:23 A.M. EST at longitude 46°12' West and latitude 76°47' South, a point in the Weddell Sea just off the coast of Antarctica.

The sky during the eclipse

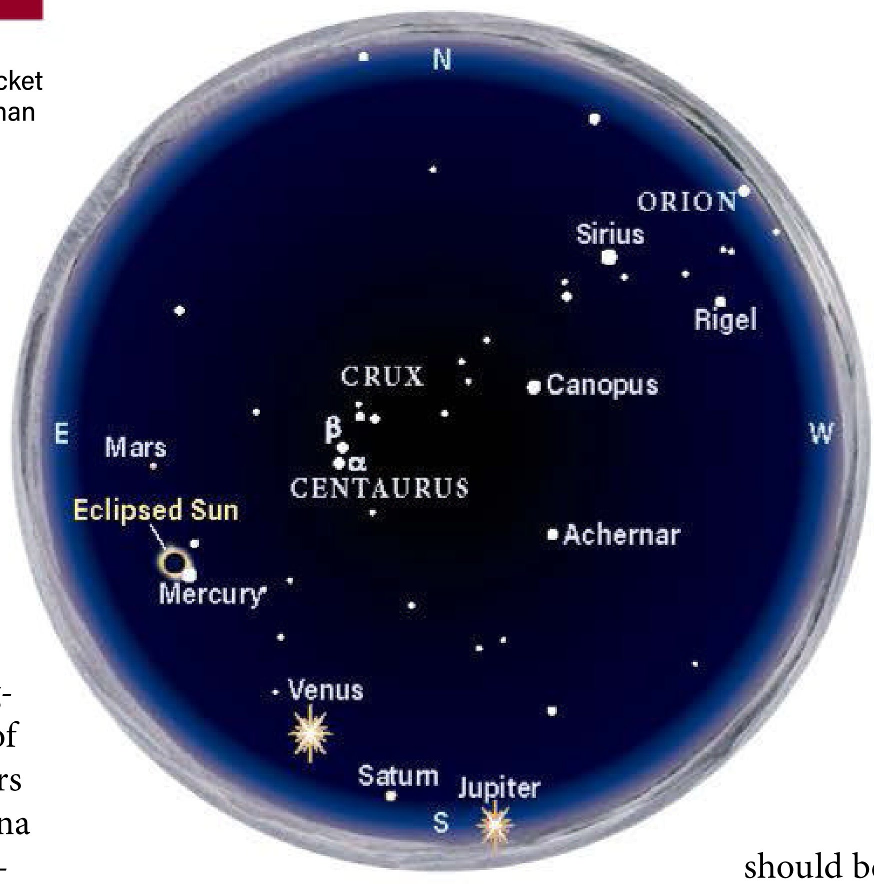
Both the Sun and Moon will lie in the southern part of the constellation Ophiuchus the Serpent-bearer. The Sun is in front of its stars from Nov. 29 through Dec. 17. At the moment of

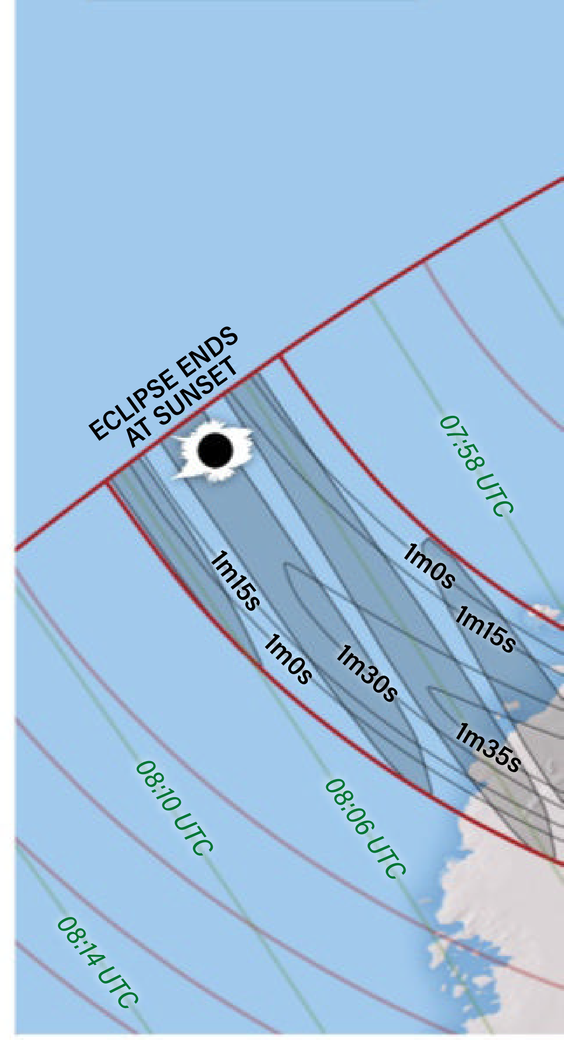
TOTAL SOLAR ECLIPSE OF DEC. 4, 2021

ANTARCTICA

ABOVE: Antarctica is a stunningly beautiful destination that should absolutely be on your bucket list. What better time to visit this remote region than during a total solar eclipse? LANDON NOLL

RIGHT: Several bright stars will be visible during totality. Additionally, Mercury will shine at magnitude –1.1 and Mars at magnitude 1.6. Due to its location 40° east of the Sun, Venus will sit low in the southeast and may not be visible. *ASTRONOMY*: ROEN KELLY





greatest eclipse, the Sun's right ascension will be 16h43m32s and its declination will be –22°16'29".

During the eclipse, the planet nearest to the Sun will be Mercury. The innermost planet, shining at magnitude –1.1, will lie 3° east-southeast of our daytime star. Sharp-eyed observers may spot it just outside the solar corona without optical aid. If you use binoculars during totality, they'll guarantee that you'll see Mercury. (Remember to use filters on your binoculars at any time other than totality.)

Venus, normally easy to spot during totality of any solar eclipse, may be invisible from its location 40° east of the Sun. That's because the Sun's maximum altitude during the eclipse is only 17°.

The shadow's journey

The South Orkney Islands, which lie in the Southern Ocean some 375 miles (600 km) northeast of the Antarctic Peninsula, are where the Moon's umbra first touches land. This small group is claimed by both Argentina and Great Britain but administered under the Antarctic Treaty System.

The western limit of the umbral path cuts through Coronation Island, the largest of the group, creating a partial eclipse for the western one-third of that small landmass. Laurie Island, which lies farthest east, fares better. The duration of totality on its western edge will be 57 seconds and will increase to 1 minute 7 seconds at its eastern coastline.

From there, the path treks southward more than 750 miles (1,200 km) to the northern coast of Antarctica. Just 44 miles (70 km) before it gets there, maximum eclipse occurs. Satellite and climate data show prospects for seeing the event improve the closer one gets to Antarctica, as December cloud cover is predicted at nearly 100 percent over the ocean path.

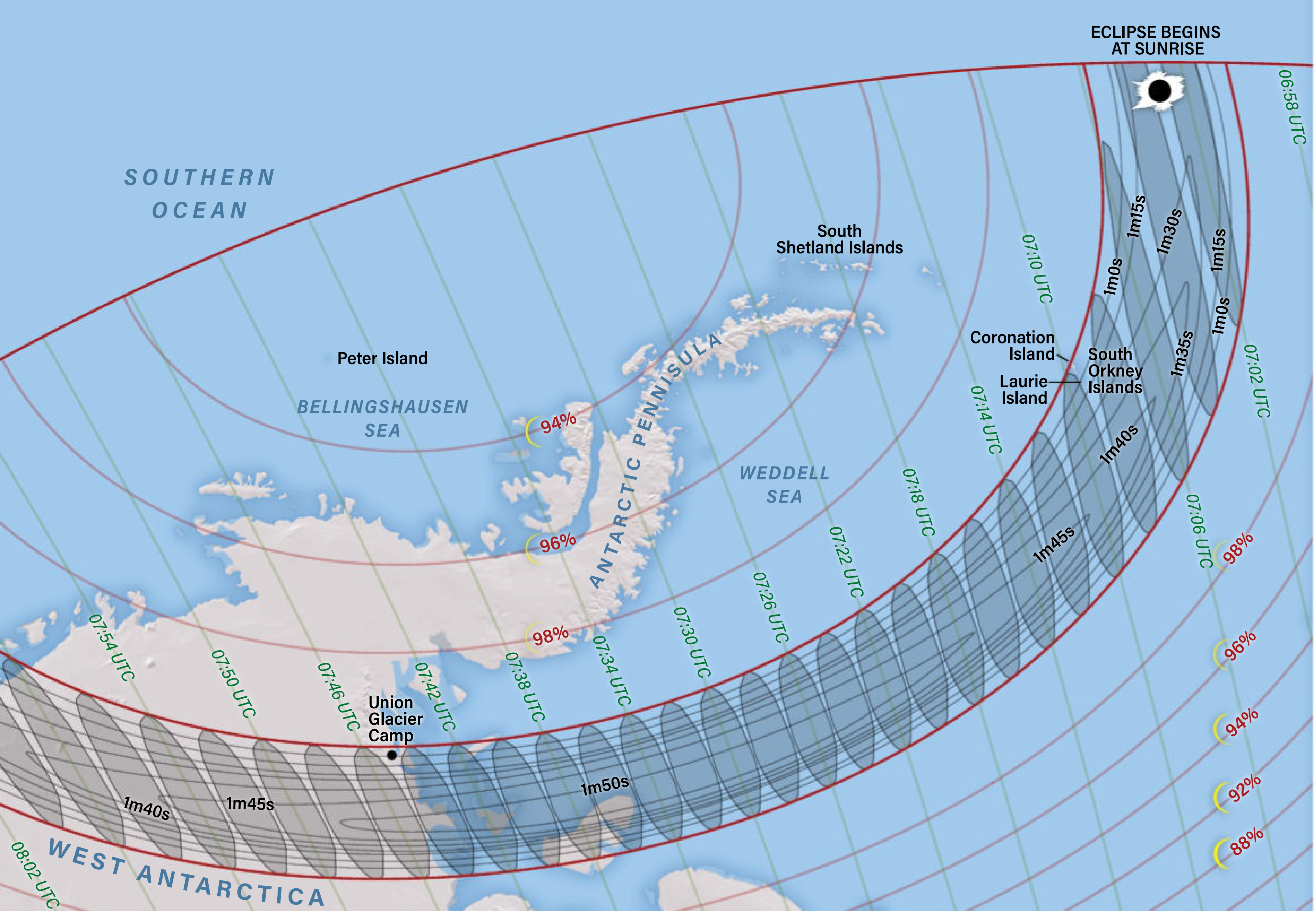
By far the best weather will be for those who can position themselves on the ice cap itself. Unfortunately, there is only one seasonal viewing site for explorers to use. Operated by Antarctic Logistics & Expeditions, this site is at Union Glacier, about 15 miles (25 km) inside the zone of totality. At the camp, the eclipsed Sun will be about 14° high and totality will last only 47 seconds, but weather prospects are better there than at any other easily approachable site along the path.

The eclipse comes during what should be nighttime hours at Union Glacier. But less than three weeks from the December solstice at the camp's latitude of 79° South, daylight stretches 24 hours. Be careful to set up where the mountains surrounding your campsite won't block your view.

Cruising to Antarctica

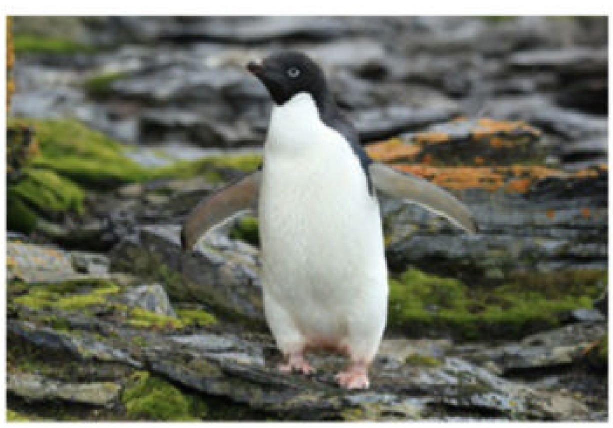
Getting to the southernmost continent can provide as much drama as the eclipse itself. Fortunately, the best months to travel to Antarctica are from November to March — the milder summer months in the Southern Hemisphere. Eclipse watchers heading there in early December will still see huge icebergs and pristine glaciers. Conditions are also optimal for viewing penguins, whales, and seals.

Most travelers start in Buenos Aires. From there, Aerolíneas Argentinas flies to Ushuaia, an Argentinian settlement on South America's southern tip, where most cruises depart. Travelers could arrive a day or two before their ship sails to stay at Arakur Ushuaia Resort & Spa



December's total solar eclipse will first touch land at the South Orkney Islands before traveling across Antarctica's northern coast. This map shows the duration of the eclipse throughout the path.
MICHAEL ZEILER/GREATAMERICANECLIPSE.COM

— the world's most southern luxury lodge — and join a day trip to the nearby Tierra del Fuego National Park. Some Antarctic expeditions depart from Hobart, the capital of Tasmania, as well as Invercargill and Bluff, which lie on the southern coast of New Zealand's South Island. This route is for the eclipse watcher with a bit more time, as the journey takes seven days.



Visitors to Coronation Island may spot species such as Adélie penguins and Antarctic fur seals.
LIAM QUINN

Boats take two days to cross the Drake Passage and stop in the South Shetland Islands to explore the Antarctic Peninsula from the Weddell Sea to Gerlache Strait. One thing to keep in mind, particularly for those who suffer from seasickness, is that the Drake Passage (Mar de Hoces), which lies between Cape Horn and the South Shetland Islands, is one of the world's roughest stretches of sea. Ships use it, however, because it's the shortest crossing between Antarctica and any other landmass.

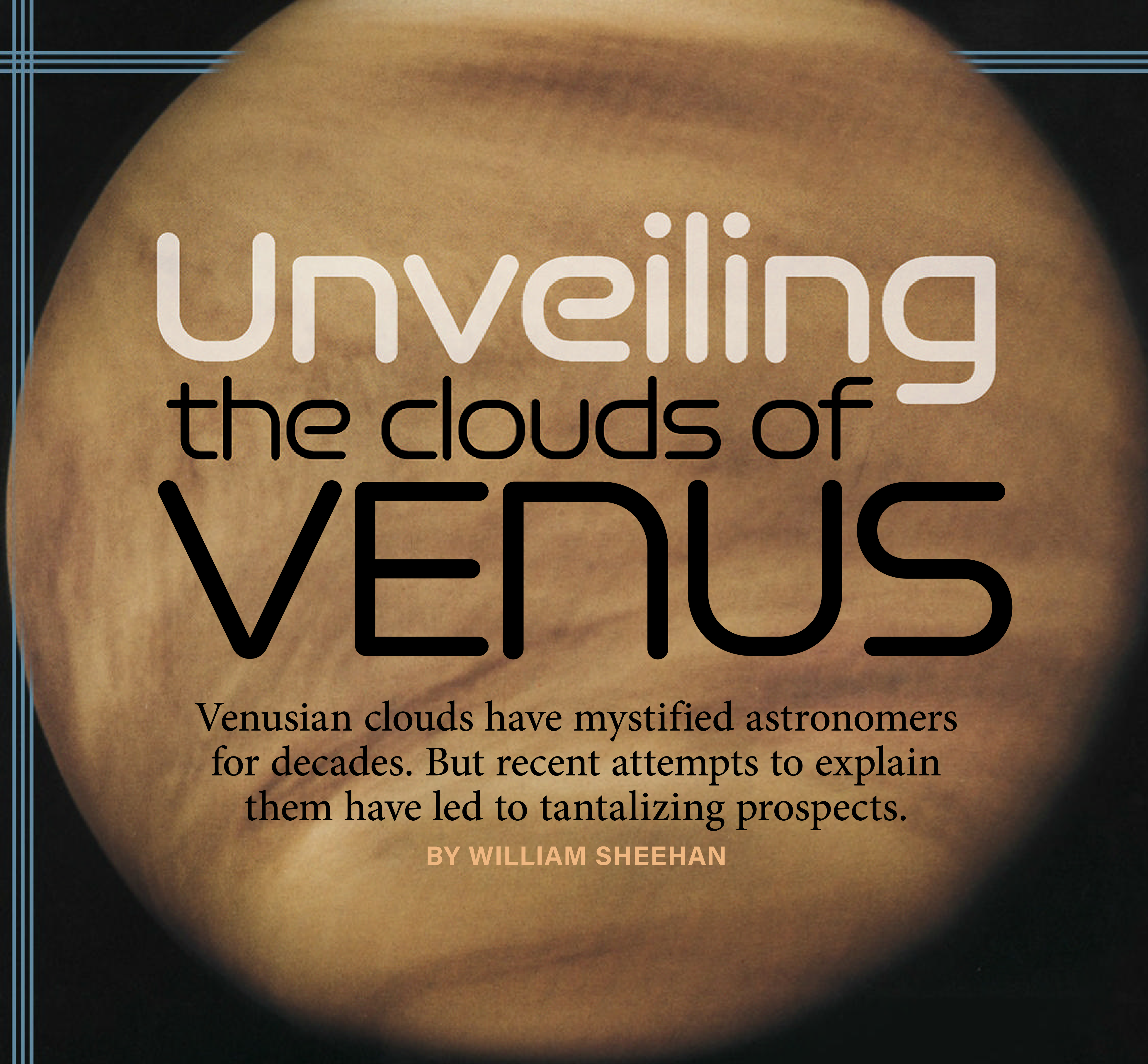
Astronomy's tour

For this eclipse, *Astronomy* magazine is once again working with TravelQuest International. In partnership with Antarctic Logistics & Expeditions, TravelQuest has created a unique expedition culminating in 44 seconds of darkness as the Moon's shadow passes over a vast expanse of ice and snow.

Instead of cruising across potentially rough waters, guests will embark on a privately chartered flight to TravelQuest's private, fully equipped camp deep in the Antarctic interior. There, travelers will spend six nights and enjoy not only organized daily activities tailored to the weather and their interests, but a special viewing of the eclipse from a site near camp. For more information, visit travelquesttours.com.

Those of you heading to Antarctica for the eclipse will create a memory that will last a lifetime. And you won't have another opportunity like this for a while: The next total solar eclipse to touch the frozen continent occurs Dec. 15, 2039.

Michael E. Bakich *is a contributing editor of* Astronomy.



Unveiling the clouds of VENUS

Venusian clouds have mystified astronomers for decades. But recent attempts to explain them have led to tantalizing prospects.

BY WILLIAM SHEEHAN

The dense clouds of Venus are on full display in this ultraviolet image taken by the Pioneer Venus Orbiter on Feb. 5, 1979. Venus' clouds have long been known to absorb ultraviolet radiation, but exactly how and why remains a mystery. NASA

AS BRILLIANT AND SPLENDID AS VENUS IS to the naked eye, the world often ranks as one of astronomy's great telescopic disappointments. Apart from its evolving phase and its dazzling, ubiquitous cloud deck, the casual observer can see very little detail.

The famed English amateur astronomer William F. Denning wrote in *Telescopic Work for Starlight Evenings* (1891): "When the telescope is directed to Venus it must be admitted that the result hardly justifies the anticipation. Observers are led to believe, from the beauty of her aspect as viewed with the unaided eye, that instrumental power will greatly enhance the picture. … But the hope is illusive." This assessment is as true today as when Denning wrote it in the late 19th century. However, with diligent courtship, and by observing with good instruments under the most favorable conditions, the so-called planet of love gradually becomes more forthcoming.

To view Venus against the backdrop of a dark sky is an exercise in futility. Instead, serious students observe it during daytime (or, at least, around sunrise or sunset), when careful study begins to reveal a few of the planet's definite features. These include the bright cusp caps and bordering dark collars, first seen in 1813 by the keen-sighted Bavarian astronomer Franz von Paula Gruithuisen with only a 2-inch refractor. Indeed, astronomers now know the caps and collars indicate polar cloud swirls — gigantic storm systems like hurricanes on Earth.

Venus certainly has no spots or belts of bold outline like those visible on Jupiter and Mars. But most patient observers will make out a few diffuse, nebulous shadings. They are rarely defined well enough to render in drawings, and hardly seem deserving of close attention. But remarkably, even in the spacecraft era, their nature remains unexplained. In fact, they pose some of the most tantalizing questions our solar system has to offer, including, some have argued, the possibility that life may have once originated on the now inhospitable surface of Venus, long ago evolving to survive exclusively in the clouds.

An unheralded 18th-century pioneer

The first noteworthy study of Venus' cloud features was made by the Rev. Francesco Bianchini, whose service to his church included the role of papal chamberlain to Pope Alexander VIII. Bianchini was a man of wide interest, a perceptive astronomer engaged in calendrical reform. And in 1726, he conducted a study of Venus as an "evening star."

To investigate Venus, Bianchini, aided by a workman, set up telescopes at various sites around Rome, including on Palatine Hill near the palace of the Caesars. His best views were obtained using telescopes made by the Roman instrument-maker Giuseppe Campani, which likely had apertures around 2.4 inches and magnifications of 112x. Starting about half an hour after sunset and continuing for as long as he could, Bianchini discovered a series of dusky spots on Venus comparable in appearance to the seas of the Moon as seen with the naked eye, though less distinct. Adding further observations during the next morning and evening, he went on to create pieces (gores) for a globe. He named the observed spots for Catholic explorers, such as Columbus, Vespucci, and Galileo, and monarchs, such as the Portuguese prince Henry the Navigator and his patron the Portuguese King John V.

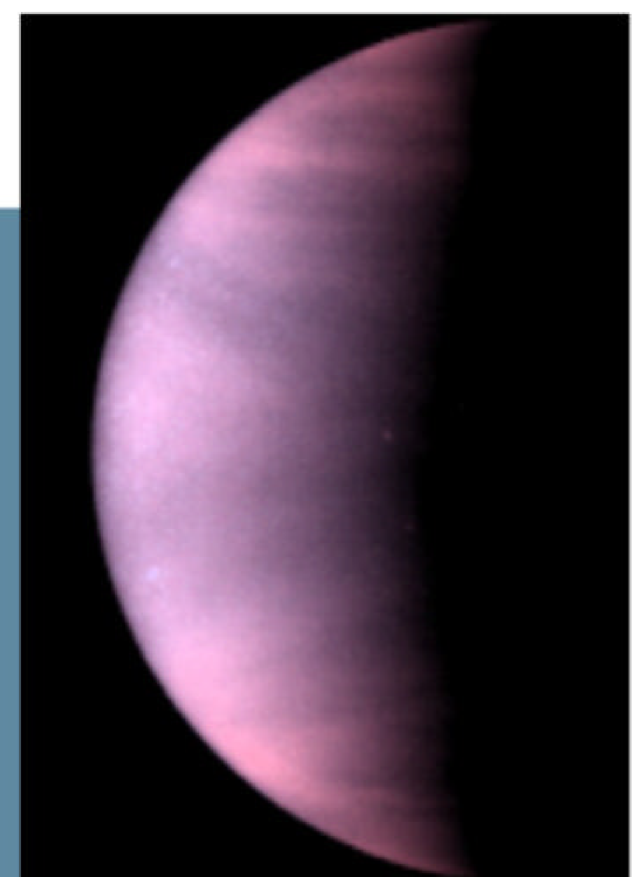
Although Bianchini's comparison of the features to lunar seas and his deduced rotation period of 24.3 days proved spurious, it seems his spots were genuine. In fact, a number of 19th-century astronomers saw similar spots on Venus, roughly circular in form and hugging the terminator. None, however, were well-defined enough to enable them to estimate a rotation period for the planet, which we know now spins backwards once about every 243 Earth days.

A strange interlude

For over a century, vague markings on Venus such as those Bianchini spotted were generally regarded to capture the essential appearance of the planet. But at the end of the 19th century, the American astronomer Percival Lowell triggered a firestorm — not with his measurement of the planet's rotation period, but with the way he perceived the features.

Using the 24-inch Clark refractor, which he set up first at Flagstaff and then at Tacubaya near the national observatory of Mexico in Mexico City, he perceived the markings of Venus to resemble the spokes of a wheel. He described these features in a flurry of articles, some with maps, which he published in scientific journals, as well as popular magazines, newspapers, and even literary outlets like *The Atlantic Monthly.* Lowell wrote that the so-called spokes were "surprisingly distinct; in the matter of contrast, as accentuated, in good seeing, as the markings on the Moon … in the matter of contour, perfectly defined throughout." He regarded them as surface features seen through the transparent veil of Venus' atmosphere and believed their motion unequivocally supported a 224.7-day rotation period for our sister world.

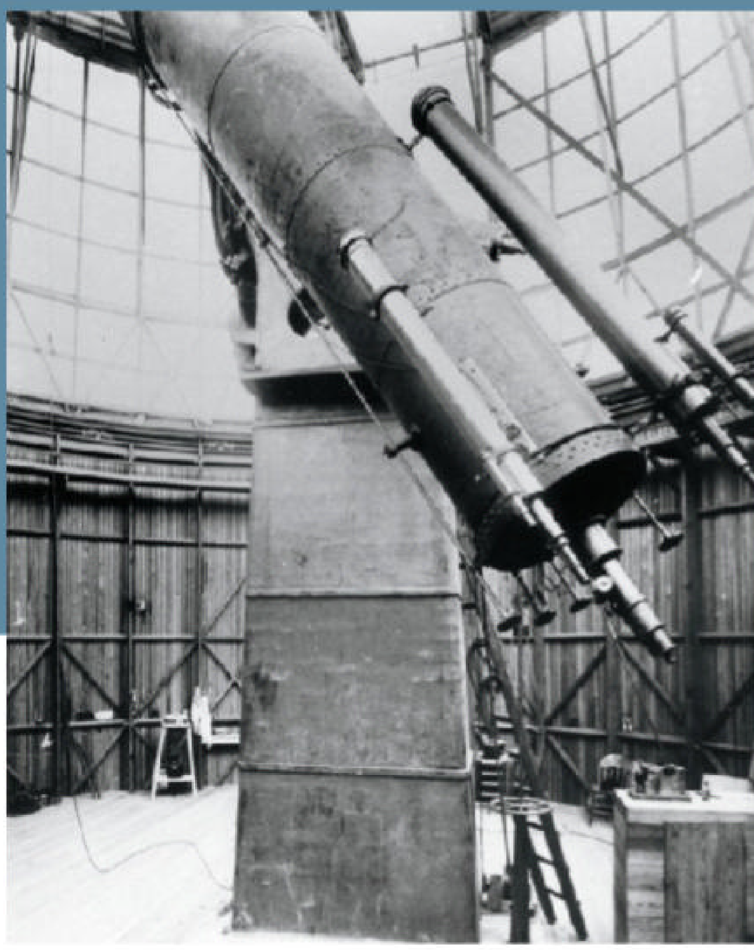
Lowell's observations and the conclusions he reached from them were, as French astronomer and author Camille Flammarion noted, "entirely at variance with all that has gone before." A few of Lowell's assistants at Flagstaff — especially his secretary, Wrexie Louise Leonard — drew the markings much like he did. But the rest of the astronomical world was unanimous in its criticism. The response was unusually harsh (though perhaps deserved) and



CLOCKWISE FROM ABOVE: Francesco Bianchini adjusts the eyepiece of a small aerial telescope while observing Venus. PIER LEONE GHEZZI

The Hubble Space Telescope captured this ultraviolet shot of Venus from 70.6 million miles (113.6 million km) away on Jan. 24, 1995. NASA/ESA/L. ESPOSITO

These sketches of Venus' clouds are based on observations Bianchini made from Italy during the evening elongation of Venus in February 1726. FRANCESCO BIANCHINI IN *HESPERI ET PHOSPHORI NOVA PHAENOMENA* (1728)



CLOCKWISE FROM RIGHT: E.E. Barnard drew this sketch of Venus in 1889 using Lick Observatory's 12-inch refractor. He described it as his best view of Venus ever. *ASTROPHYSICAL JOURNAL*

The globe of Venus photographed here is located in Oxford's Christ Church Library, and based on the map published by Bianchini in *Hesperi et Phosphori nova phaenomena*. WILLIAM SHEEHAN

The Clark Telescope is seen mounted beneath a canvas-covered dome in Tacubaya, Mexico, in this shot from 1896. It remained at the site for several months. LOWELL OBSERVATORY ARCHIVES

contributed to Lowell's nervous breakdown when he came back from Mexico. Nonetheless, he held forth on the reality of his markings after he returned to Flagstaff in 1901. His first order of business was acquiring a Brashear spectrograph and placing it in the hands of his assistant, Vesto Melvin Slipher, so that he might confirm the longer rotation period and buttress the original Flagstaff observations. Lowell never disavowed the spokelike markings, and he and his assistants continued to draw the linear features when sketching Venus, though the later marks were not as regular as those initially reported. In general, as with his observations of the canals of Mars, Lowell's work cast considerable doubt on the worth of visual studies of the planets.

According to famed English amateur astronomer Sir Patrick Moore, whose book *The Planet Venus* (Macmillan, 1958) was the bible of Venus studies during that era: "Visual observations made at the eye-end of a telescope are of little use to us here, so we must turn instead to photographic results."

Photos to the rescue

At first, photography of Venus yielded no more insight than visual observations. It seems that French astronomer Ferdinand Quénisset made the maiden attempt at venusian photography in 1911 at Camille Flammarion Observatory in Juvisy-sur-Orge, France, imaging the planet in visible light. The new view, however, showed very little. The real breakthrough came when Frank Elmore Ross of the Yerkes Observatory photographed Mars and Venus using colored filters during a sabbatical year at Mount Wilson in 1926/27. Before coming to Yerkes, Ross had spent nearly a decade at Eastman Kodak investigating photographic emulsions and filters, so he was well informed on the latest technology.

During Venus' exceptionally favorable elongation in June 1927, Ross imaged the world with Mount Wilson's 60- and 100-inch reflectors over 25 nights, in as nearly unbroken a series as practicable. The visible light images were featureless. But Ross held out hope for his infrared ones, since such filters had been used in terrestrial aerial photography to penetrate haze. Unfortunately, even the infrared shots proved equally bland and featureless. But Ross did obtain stunning results using a just-released Eastman Kodak Wratten 18A UV (ultraviolet) filter. They revealed a plethora of details, showing dark markings generally in the form of bands running parallel to the planet's presumed equator and joining up at roughly right angles to the terminator.

Ross's interpretation of this new class of features was necessarily tentative. In a 1927 paper in the *Astrophysical Journal*, he suggested they might represent "variations in structure of a thin layer of cirrus clouds which overlie the dense yellow lower atmosphere, due undoubtedly to violent disturbances originating far below, perhaps near the surface of the planet itself." Based on his best estimate from his data, he suggested the planet's rotation period was 30 days.

Boyer's day

For whatever reason, nobody immediately followed up on Ross' discovery of UV markings on Venus. Earl Carl Slipher, Vesto Slipher's brother, did begin photographing the world in UV the following year. He kept at the series until 1948 but did not publish his work until 1964. A series of UV photographs taken by Robert S. Richardson at Mount

Wilson in 1954 also brought nothing new. It was 30 years before anyone added anything significant to Ross' insights — and it came not from a professional astronomer, but an amateur.

Born in Toulouse, France, in 1911, Charles Boyer spent many years in equatorial Africa in the French judicial service. A ham radio enthusiast, he made contact with fellow enthusiast Henri Camichel, an astronomer at the famed Pic du Midi Observatory in the French Pyrenees. Camichel encouraged Boyer's fledgling interest in the planets. At Boyer's site (4° south of the equator), the planets were often high in the sky. Realizing the opportunity for first-rate observations, Boyer built his own 10-inch Newtonian reflector around a mirror fashioned by the renowned French optician Jean Texereau. Although his scope was set up on a rather primitive alt-azimuth mount, Boyer devised a way (using parts from a Meccano set) to move the camera across the focal plane of his telescope to properly track the sky. He asked Camichel to suggest an observing project. And Camichel, who was just then photographing Venus in UV from Pic du Midi, suggested Boyer also give it a try.

In August and September 1957, Boyer set to work. Lacking a proper UV filter, he made do with a blue-violet Wratten 34 filter. The images were small and aesthetically unappealing, but they recorded what seemed to be a dusky region in Venus' atmosphere that returned to the terminator at roughly four-day intervals. Camichel checked his images against Boyer's, finding further evidence in support of this period. The observing campaign continued until 1960, at which point the two men concluded that a four-day rotation of the upper atmosphere was "completely uncontestable."

However, the result was still greeted with skepticism — not least by Carl Sagan. As the then-editor of the planetary science journal *Icarus*, Sagan rejected an early paper that Boyer and Camichel submitted. It wasn't until 1974 that the four-day rotation of Venus' upper atmosphere was confirmed when Mariner 10 carried out UV imaging of the clouds during a flyby en route to Mercury.

By then, astronomers using radar had discovered that the rotation of the solid body of the planet was slow and retrograde, with a period of 243 days. This meant that Venus's atmosphere experienced "super-rotation," spinning some 60 times faster than its surface. But how could Venus' atmosphere overcome surface friction and acquire so much angular momentum that it could spin so quickly? For a long time, this was a complete mystery. But recent spacecraft observations suggest that thermal tides generated by the Sun's periodic heating of Venus' atmosphere may be the source of the excess angular momentum.

So, what is responsible for the dark markings that rapidly circle that other world?

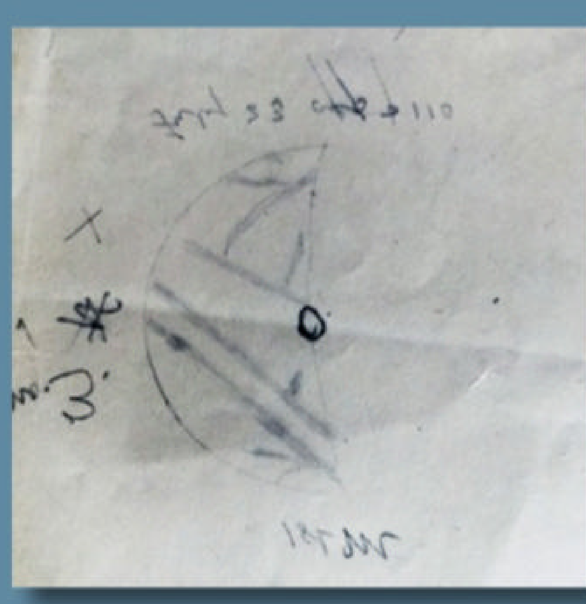
Another mystery, which remains unsolved, is the identity of the UV absorbers responsible for the dark bands found in photographs and corresponding to the nebulous shadings sometimes seen by visual observers.

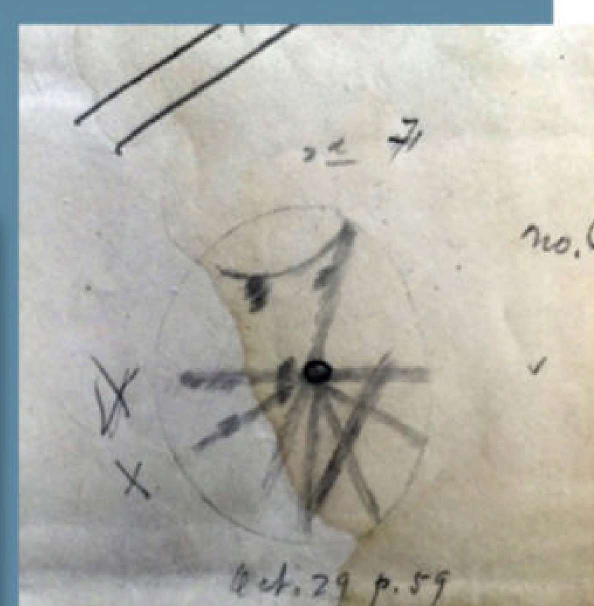
UV absorber enigma: Life in the clouds?

So, what is responsible for the dark markings that rapidly circle that other world? Surprisingly, we still don't know. The nature of the UV absorbers remains, almost a century after Ross's photos, one of the great enigmas of Venus.

What we do know is that whatever is doing the absorbing resides in the thick sulfuric acid droplet cloud layer that spans from 30 miles (48 kilometers) to 43.5 miles (70 km) in altitude. At the lower end of the range, the temperature is some 230 degrees Fahrenheit (110 degrees Celsius) and the pressure is about twice that of Earth at sea level. At the upper end of the range, the temperature is 113 F (45 C) and the pressure is just 4 percent that of Earth at sea level. Scientists have identified some compounds in the clouds' higher reaches, of which the sulfur-bearing species disulfur oxide (S_2O) and disulfur dioxide (S_2O_2) give the best fit to the absorption spectrum. But this work still has a long way to go to unequivocally identify the UV absorber (or absorbers) on Venus. As V.A. Krasnopolsky of the Catholic University of America and Moscow Institute of Physics and Technology, the first person to construct a photochemical model for the atmosphere of Venus above the cloud layer, concludes in a 2021 paper in *Icarus*, "there is no general agreement on the nature of the UV absorber in Venus, and thus this remains as one of the most intriguing open questions in planetary atmospheres." Furthermore, whatever UV absorbers lie in the atmosphere's lower layers, beyond our observations, remain even more elusive.

There's also another, more exotic possibility: microbes of some kind, living and floating in the clouds of Venus. As far back as 1967, when the Soviets'





Wrexie Louise Leonard, Percival Lowell's secretary, sketched the "spoke system" of Venus on Oct. 29, 1896 (left), and Feb. 23, 1897 (right), using the 24-inch Clark refractor at Tacubaya, Mexico. LOWELL OBSERVATORY ARCHIVES

Venera 4 spacecraft probed Venus' atmosphere for the first time, Carl Sagan and Howard Morowitz put forth the idea of cloud-dwelling venusian microorganisms. They knew, of course, that life on the surface seemed impossible. The surface pressure of Venus' nearly pure carbon dioxide atmosphere is some 90 times that of Earth, comparable to the pressure at a depth of nearly 3,000 feet (900 meters) in Earth's ocean. Plus, driven by a runaway greenhouse effect, the surface temperature is a scorching 878 F (470 C). Not even thermophilic (heat-loving) microorganisms on Earth could survive such conditions. Though some thermophiles can thrive at temperatures as high as 235 F (113 C) — higher than the boiling point of water — when temperatures climb higher, the biomolecules that make up the organisms break apart within seconds. Therefore, based on our current understanding of life, Venus' surface must be utterly sterile.

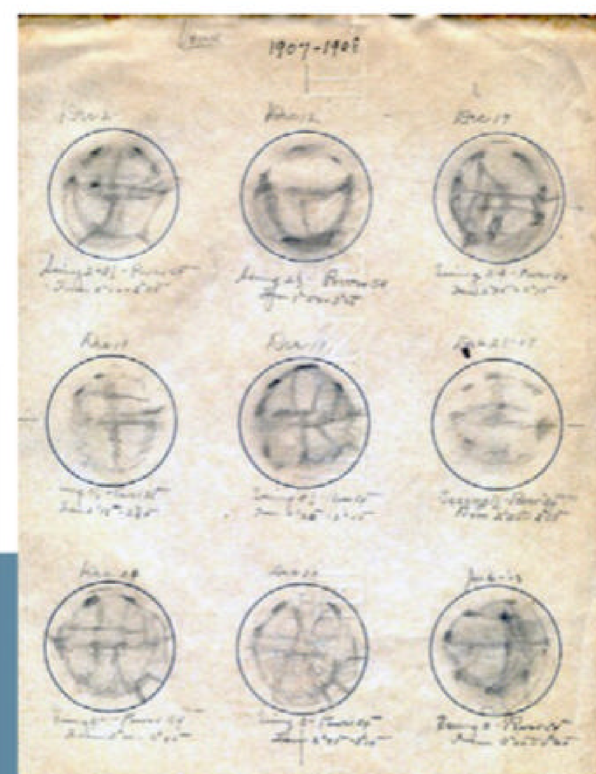
But suppose that at some point in the distant past, microbes that originated on the once-habitable surface escaped into the cooler clouds, making them their home. There has always been a small number of scientists willing to entertain this rather speculative idea. In 1975, after showing that the decrease in reflectivity of Venus' clouds in near-UV light could be explained if the clouds contained particles of elemental sulfur and sulfuric acid, Bruce Hapke and Robert Nelson at the University of Pittsburgh concluded in a 1975 paper in *Journal of Atmospheric Sciences*, "We cannot resist pointing out that many examples of anaerobic, terrestrial organisms are known in which the reduction or oxidation of various forms of sulfur are important sources of energy in their metabolisms."

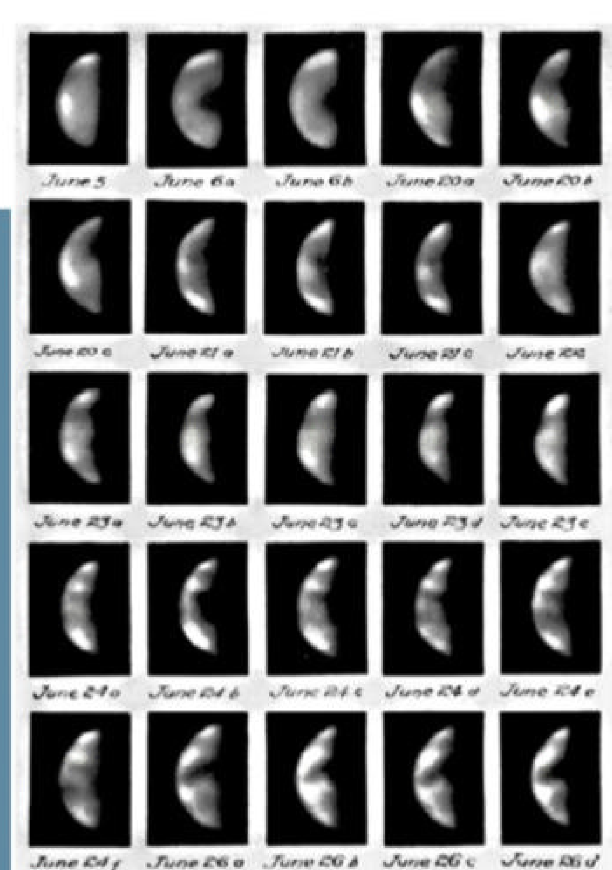
There is another, more exotic possibility: microbes of some kind.

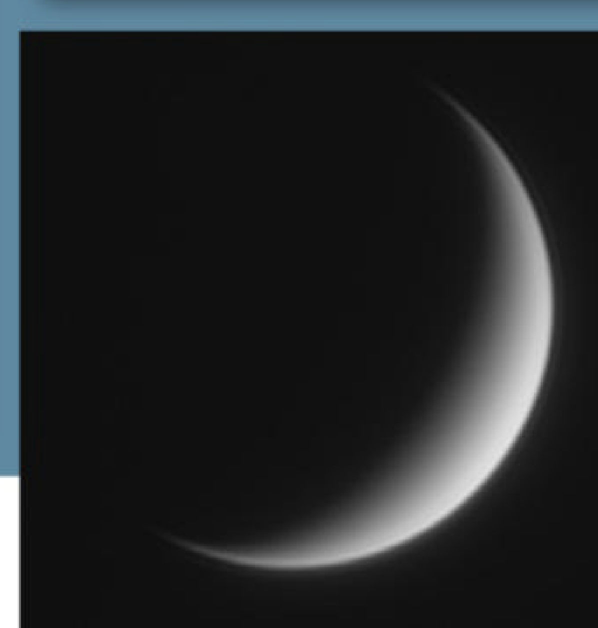
And nearly three decades after finishing his work on the rotation of Venus' upper clouds, in 1986, Boyer proposed in the French popular astronomy journal *L'Astronomie* that the clouds' dark markings might consist of vast sheets of photosynthesizing organisms. These sheets would behave much like the algal blooms in our oceans, growing in size until the available nutrients are depleted and then dying out, all over a matter of a few Earth days. A couple of years later, American planetary scientist David Grinspoon speculated that a photosynthetic pigment might be the unknown ultraviolet absorber. In the early 2000s, Dirk Schulze-Makuch and Patrick Irwin made the obvious (if controversial) suggestion that such venusian organisms could be heat-resistant sulfur-based archaea like those discovered in the hot springs of Yellowstone or near deep-ocean hydrothermal vents.

However, there are a number of difficulties surrounding the theories of microorganisms living in the clouds of Venus that have yet to be overcome. For such life to have developed on Venus, there must have once been oceans on the world, or at least surface lakes and puddles. But over the past few hundred million years, the entire surface of Venus has been re-formed by simultaneous volcanic eruptions of large igneous provinces, obliterating the early surface. Thus, studying its history is quite difficult.

Although the surface of Venus is now a Dantean inferno, let's suppose that microbial life did form on the world at some point in its past. Could that life have then hitched a ride on a thermal stream, as microorganisms do on Earth, and evolved to survive at extreme heights? There are no Earth analogues that do this; although floating microorganisms on Earth can remain in the atmosphere for days, they must come down to reproduce. But





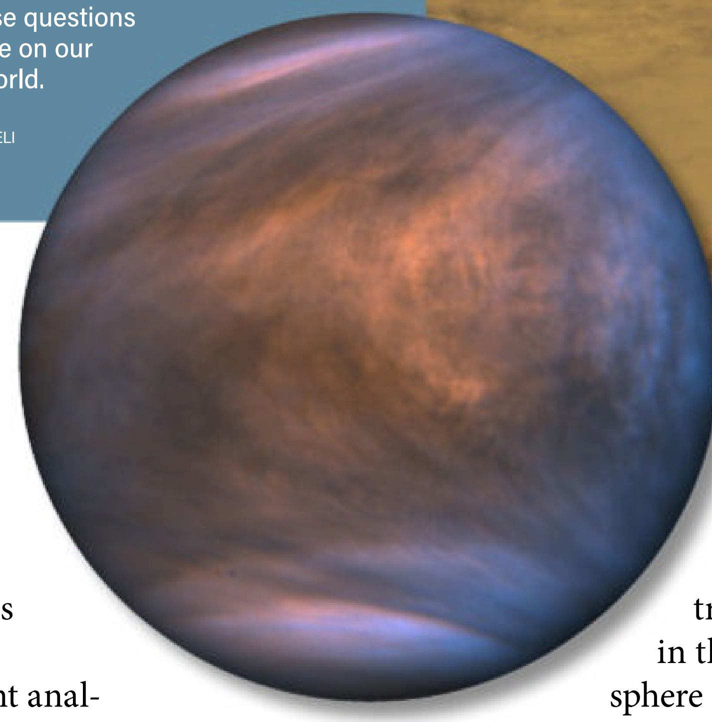


CLOCKWISE FROM TOP RIGHT: Earl C. Slipher made these sketches of Venus between December 1907 and January 1908. In addition to being a world-renowned photographer of the planets, Slipher was an assiduous visual observer. He also observed canals on Mars, recording them much as his employer, Percival Lowell, saw them. LOWELL OBSERVATORY ARCHIVES

Venus appears bland and featureless in infrared images like this, as it does in visible wavelengths. This shot was captured by William Leatherbarrow of Sheffield, England, using a 12-inch Maksutov-Cassegrain telescope with a 742nm pass filter. WILLIAM LEATHERBARROW

Frank E. Ross took these ultraviolet images of Venus in June 1927 with the 60-inch and 100-inch reflectors at Mount Wilson Observatory. *ASTROPHYSICAL JOURNAL* (1928)

RIGHT: Planned for launch in 2029, NASA's DAVINCI spacecraft will descend through Venus' atmosphere, as seen in this artist's concept, while taking measurements of the clouds' composition. The data from the ambitious mission will help scientists better understand how Venus formed and evolved. NASA



BELOW: Japan's Akatsuki spacecraft, which has been orbiting Venus since 2015, shot this image of the planet and its thick clouds in ultraviolet light. Astronomers recently found evidence that ample phosphine — a chemical largely produced by life here on Earth — is prevalent in the atmosphere of Venus. Although the results are controversial, they raise questions about life on our sister world. ISAS/JAXA/AKATSUKI/MELI THEV

perhaps microorganisms on Venus evolved along with the changing conditions in the atmosphere. As Ian Malcom says in *Jurassic Park*: "Life finds a way."

The extreme acidity of Venus' atmosphere is another problem for life, despite the fact there are some archaea that survive in extreme environments on Earth where the pH is around 1, which is comparable to the acidity of Venus' upper clouds. If Venus microbes do exist, they likely would have had to evolve some sort of protective membrane to survive in the harsh, high-acidity environment.

Maybe Venus' clouds are sown with airborne microbes resembling sulfur-reducing autotrophs on Earth, which are able to reduce elemental sulfur to hydrogen sulfide, and therefore thrive in the absence of oxygen. Or perhaps they resemble some types of photosynthesizing organisms, whose peak absorption is of blue-violet or ultraviolet light instead of the blue, yellow, and red light that terrestrial analogues like algae and plants optimally absorb. As discussed in a paper by Sanjay Limaye of the University of Wisconsin-Madison and his colleagues in 2018, there are many compounds that absorb the same wavelengths of light found in the absorption bands of Venus' spectrum. These include iron-containing proteins like heme (a precursor to hemoglobin), iron sulfide (the most common sulfide mineral in the Earth's crust, which is found in hydrothermal deposits like those at Yellowstone), and photosynthetic pigments like chlorophylls. Indeed, the absorption spectrum of *Thiobacillus ferrosxidans*, a highly acidophilic (pH 1.5 to 2.0) bacterium that obtains its energy through the oxidation of ferrous iron or reduced inorganic sulfur compounds, is markedly similar to the spectrum of Venus' clouds.

There are also the recent claims of the detection of phosphine in Venus' clouds, which has spurred significant debate in the scientific community. That's because microorganisms produce the gas on Earth, and phosphine production requires a reducing atmosphere — one that removes oxygen. Reducing compounds such as methane, ammonia, amino acids, and the like are not stable in an oxidized atmosphere because they oxidize. So for a gas like phosphine to be in Venus' clouds, it is necessary for it to be replenished somehow. But exactly how has yet to be determined. A recent analysis (published in March in *Geophysical Research Letters*) of data obtained for Venus' middle cloud layers by the Pioneer Venus mission in 1978 supports the potential existence of phosphine, as well as traces of several other compounds consistent with the presence of a reducing atmosphere, which venusian microorganisms could use to support metabolic processes. On the other hand, some researchers dispute this, arguing that volcanic eruptions on the surface or lightning strikes in the clouds could explain the phosphine surplus.

Searching for an answer

At the moment, we simply don't know exactly what's going on in Venus' clouds. But in any case, their potential habitability is no longer a fringe idea. Indeed, it was among the considerations that led NASA planners to recently approve two spacecraft to Earth's sister planet. Known as VERITAS (Venus Emissivity, Radio Science, InSAR, Topography and Spectroscopy) and DAVINCI (Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging), the missions are scheduled for launch between 2028 and 2030. Notably, DAVINCI will gather profiles on the trace molecules present in the venusian atmosphere — including possible UV absorbers — as it descends through the clouds toward the surface. Additionally, the Russian space agency Roscosmos is planning to launch (with NASA collaboration) Venera-D in 2028 or 2029. This would be followed by three more missions in the 2030s, culminating with a surface sample returned from Venus. Meanwhile, the European Space Agency has approved EnVision, a mission similar to VERITAS in that it will map the planet's surface topography and composition. Long neglected compared to Earth's other neighbor, Venus is about to become a rather busy place.

It seems likely that — at long last — these missions will allow unequivocal identification of the mysterious UV absorbers residing in the clouds of Venus. Whatever they prove to be, organic or inorganic, by identifying them we will reach the end of a trail that began with Bianchini, Ross, Boyer, and others. But even then, the strange features will surely summon imagers and visual observers of Venus to the telescope for years to come.

William Sheehan *has written 20 books on astronomy, including* Venus *with Sanjay Limaye (Reaktion Books, 2021).*

Defining TIME

Even though time has existed since the beginning of, well, time, it was still necessary to invent it.

BY RAYMOND SHUBINSKI

TIME AND ASTRONOMY ARE INSEPARABLE. Humans have been using the motions of the stars, Sun, and Moon for thousands of years to regulate their hunting, crops, religion, and lives in every way. And as astronomy developed, so did the need for more precise timekeeping.

There are many ways to ask, "What is the time?" Astronomers can use solar standard time, mean solar time, sidereal time, Universal Time, or Julian Date and its many modified forms. Astronomers describe three different types of twilight, the equation of time, 24 time zones, and an astronomical day. Understanding these different "times" gives us a better idea of our relationship with the sky above, and the spinning Earth on which we live.

The beginning of time

Early civilizations developed two types of calendars. The oldest is lunar in nature. It might seem more logical for the Sun to have been the first timekeeper, but archaeologists have found bones of mammoths and other animals dating over 20,000 years old that appear to have carvings recording phases of the Moon. During that period of human history, hunters tracking game needed to know how long they had been gone from their camp, making the Moon the obvious choice to track the passage of time.

It would be millennia before the Sun replaced the Moon in our modern calendar. This is because Earth and the Moon are involved in a cosmic mashup that is difficult to untangle. Most ancient cultures heralded the beginning of the month when the thin crescent or "New Moon" could be seen after sunset. There are 354 and a fraction days in a lunar year with 12 lunar months. Earth, however, revolves around the Sun every 365.242 days. While this was not a problem in a purely ceremonial or religious calendar, trying to mesh these two calendars was impossible.

The solution to this issue was proposed by Sosigenes of Alexandria, Cleopatra's court astronomer and arguably the most influential astronomer in all of history. Julius Caesar

The Samrat Yantra (above) is the largest purpose-built sundial in the world, with its gnomon — or tower — standing 73 feet (27 m) high. Built in the early 18th century, the massive instrument is part of the Jantar Mantar observatory in Jaipur, India. The gnomon (left) casts a shadow onto the flanking quadrant arcs, which can indicate the time to an accuracy of two seconds. ABOVE: JORGE LÁSCAR, CC BY 2.0. LEFT: JAKUB HAŁUN CC BY-SA 4.0

BURNED PARCHMENT: ALEKLEKS/DREAMSTIME; CLOCK COGS: DVMSIMAGES/DREAMSTIME

employed Sosigenes to fix the old Roman lunar calendar. By Caesar's time, the lunar calendar had become so out of sync with the seasons that it required a decree from the emperor to remedy the situation. At Sosigenes' suggestion, the old lunar calendar was replaced with one which used only the Sun to delineate the year. The Moon was left to drift through the 12 months of Caesar's new calendar.

This Julian calendar also implemented leap years, adding one extra day every four years. But this was not quite a perfect fix, as the last fraction of a day in a year is slightly less than one-quarter of a day. By the 16th century, the Julian calendar was also out of step with the seasons. This led Pope Gregory XIII to implement updates in 1582 that dictated leap years be skipped on years divisible by 100 except when divisible by 400. So while 1900 was not a leap year, 2000 was. Two thousand years later, the whole world still uses the modified calendar of Sosigenes.

Keeping time

Cultures the world over developed methods for tracking the hours using water clocks, hourglasses, and sundials, often for the purpose of scheduling religious rituals. Of course, there were limitations to these methods. Water froze in the winter, hourglasses needed to be turned over, and sundials were of no use after sunset.

Around the year A.D. 1000, mechanical devices that could ring bells to tell time began to appear in western Europe. In fact, some think the word "clock" derives from the French, *cloche*, meaning bell. These early mechanisms had no dials and only rang bells. Within a few hundred years, dials were added to visually

show the hour. By the 13th century, astronomer monks were creating complex movements with dials that had an hour hand and displayed Moon phases, the solstices, and equinoxes, and more.

In the Middle Ages, knowing the hour was sufficient for everyday activity. Words like *moment* meant the passage of 15 minutes rather than a blink of an eye. As astronomy advanced, however, more precision was needed. This came courtesy of the regular motion of swinging pendulums, which Galileo studied at the beginning of the 17th century. In 1657, the Dutch astronomer Christiaan Huygens applied for a patent for a clock using the regular oscillation of a swinging pendulum to regulate the passage of time. Clocks were now accurate enough to not only justify both an hour and minute hand, but a second hand as well.

Navigating by time

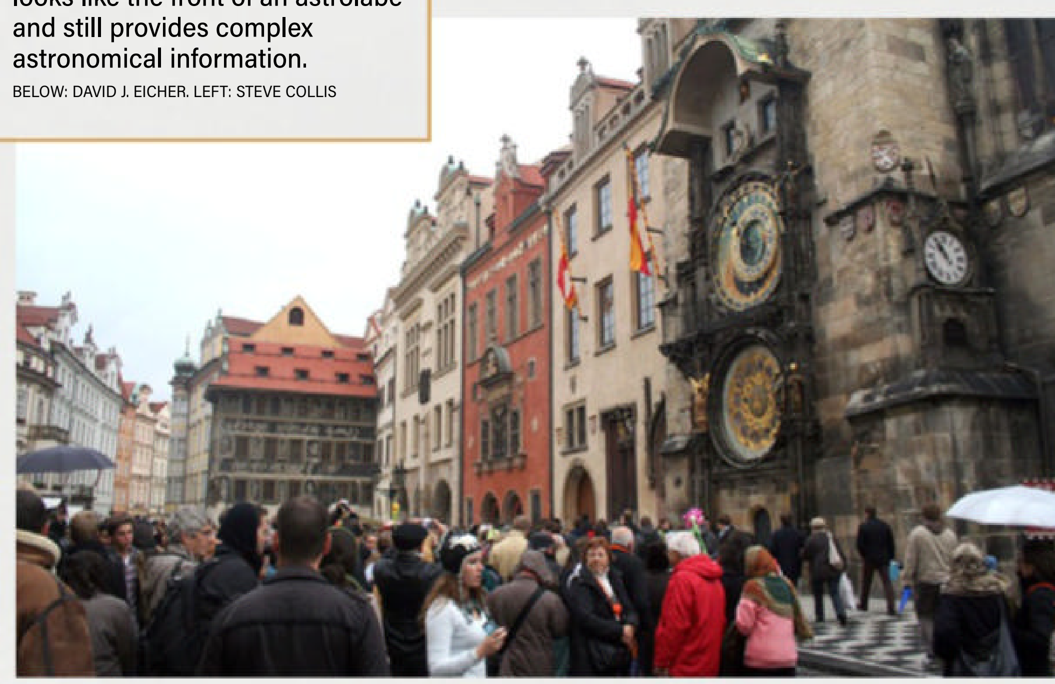
Science, technology, and commerce often complement each other. In the 17th century, the three came together to tackle the difficult challenge of determining a ship's longitude at sea.

In 1676, at the newly built Greenwich Observatory located outside of London, two unique clocks with 13-foot-long (4 meters) pendulums were installed. These clocks were accurate to within 10 seconds over the course of a day or better, dramatically increasing astronomers' ability to make accurate observations.

The first astronomer royal, Sir John Flamsteed, wanted to know if Earth's rotation was isochronical. In short, did Earth spin on its axis at a constant rate? With the new clocks, Flamsteed showed that the spinning of our planet was in fact constant. This provided the first link in the efforts to solve the longitude problem.

By the 18th century, navigators were using portable clocks driven by wound springs that could accurately maintain Greenwich time. By comparing them to their observed local solar time, they could determine their longitude hundreds of miles from land-based observatories.

One of the most famous astronomical clocks (below) can be found down a side street in the old city of Prague. Built in 1410, it has been operating for more than 600 years. The beautiful dial (left) looks like the front of an astrolabe and still provides complex astronomical information.
BELOW: DAVID J. EICHER. LEFT: STEVE COLLIS



Syncing time

As the 19th century neared, clocks and pocket watches had become common and fashionable. But how did you set them? With the garden sundial! When travel was by foot or horse, differences in "local" times were negligible and did not present a problem. But with the arrival of trains, all of this changed, and astronomy came to the rescue once more.

For every 15° of longitude either west or east of a designated meridian, the local solar time decreases or increases by one hour. That means for each degree of longitude, time changes by four minutes. If there is a sundial that shows noon at Greenwich, it would be 11:40 A.M. by a sundial in Oxford. Across Great Britain, there is a 30-minute difference in time. This was hard enough for railroads in a small country where every town adjusted its clocks to the local sundial. It was worse in North America, where time zones spanned three and a half hours! Each town used local sundials to set their clocks, while each railroad had a different standardized time for their published timetables. This made it almost impossible to have rail schedules that made any sense at all.

To solve this, astronomers divided the globe into 24 time zones. The starting point for these time zones was based on the meridian defined by specific observatories that made noon day observations. In England, it was the Greenwich Observatory, France used the observatory in Paris, and the U.S. used the

Naval Observatory in Washington, D.C.

As telegraphs encircled the globe, it became possible to transmit time signals. In 1833, the Greenwich Observatory installed a bright red "time ball" mounted to a mast on the observatory roof. The ball dropped at precisely 1 P.M. every day, allowing ships on the River Thames to set their chronometers in reference to the observatory clock. By 1850, Astronomer Royal Sir George Airy was interested in "electrifying" time. Airy felt it was a national duty to provide Greenwich time to the nation. Daily time signals were being sent across England by the 1870s.

LEFT: Greenwich Observatory stands on a hill overlooking the River Thames, which allowed nearby ships to set their clocks to the time ball on its roof. Time balls grew in popularity through the late 19th century and inspired the annual New Year's midnight ball drop in New York City's Times Square. DAVID J. EICHER

BELOW: In March 1911, English newspapers took pleasure in reporting that Gallic clocks were being turned back to Greenwich time, as evidenced by this illustration in the *Illustrated London News*. COURTESY RAYMOND SHUBINSKI

BRINGING PARIS INTO LINE WITH GREENWICH: THE NEW FRENCH TIME.

In America, astronomers also began to distribute time. The U.S. Naval Observatory sent occasional time signals as early as 1865. By 1869, the Allegheny Observatory near Pittsburgh began a time service for an area spanning New York, Chicago, and beyond. The signal was sent to railroads and jewelry stores. Jewelers placed connected clocks in their windows where customers could set their watches. Allegheny and other observatories charged fees to distribute these time services, allowing them to fund important astronomical research. Time really was money.

By the late 19th century, the situation had taken on international dimensions. In October 1884, delegates from around the world gathered in Washington, D.C., at the International Meridian Conference. The goal was to determine "a common zero of longitude." Each of the 24 world time zones would be reckoned from one prime meridian and standardized to mean solar time. Thus, the beloved sundial was relegated to gardens and church cemeteries.

The meridian of the Greenwich Observatory was chosen as the zero point for the world's time zones. The decision was made in part because of Greenwich's historical association with timekeeping, and the fact that the United Kingdom still dominated maritime commerce. Not all of the 35 delegates were happy. In particular, the French insisted the prime meridian not be tied to any one nation and should be neutral. French clocks continued to use time issued from the Paris Observatory. They remained 9 minutes and 21 seconds ahead of Greenwich Mean Time (GMT) until March 10, 1911. Apparently, even time can be political.

Counting the days

Astronomers thrive on precision, and calendar dates can often be cumbersome and confusing. To be more precise, observations and events are often recorded by their Julian Date. The Julian period was the brainchild of the 16th century historian Joseph Justus Scaliger and begins on Jan. 1, 4713 B.C. This date is one where several cycles coincide: the 28-year solar cycle in the Julian calendar, after which the days of the year fall on the same days of the week; the 19-year Metonic cycle, when lunar phases recur on the same days of the year; and the 15-year indiction cycle, the tax cycle of the Roman Empire, which was another method for recording dates.

When John Herschel adapted Scaliger's idea for astronomical use in 1849, he chose noon as the zero hour for the current Julian Period, thus avoiding a date change during nighttime observations. Julian Date is then simply the number of days that have passed since noon on Jan. 1, 4713 B.C.

In 1957, the Smithsonian Astrophysical Observatory created a Modified Julian Date, which begins at midnight GMT, Nov. 17, 1858. This made the day count considerably smaller and more manageable for early computers.

Time and astronomy are rooted in the way we order our lives. Ancient sky watchers looked to the sky to bring order to their world, and we still use astronomical cycles to set the very patterns of our lives. Astronomers have given these patterns order and precision in an effort to answer that age-old question: "What time is it?"

Raymond Shubinski *is a contributing editor of* Astronomy. *He loves winding his clocks and keeping time with the cosmos under the clear skies of the Great Southwest.*

TONY HALLAS

Capture the sky with Stellarvue's SVX 102T

The 4-inch refractor has been a favorite of astronomy enthusiasts for countless years, thanks to the combination of portability and resolving power. While these scopes are not the largest light buckets around, they lend themselves well to wide-field observing.

Recently, I revisited this classic format. After acquiring a new full-frame camera (the QHY 128C Pro), I needed to find a wide-field telescope to go with it. Careful research led to my selection: Stellarvue's SVX 102T refractor.

This scope is perfect for astrophotographers and visual observers alike.

BY TONY HALLAS

The nitty gritty

The SVX 102T has a length of 23.5 inches (59.7 centimeters) with the focuser attached, and the dew shield adds an additional 5.5 inches (14 cm). It weighs 9.8 pounds (4.4 kilograms) with both the 2-inch and 1¼-inch ring adapters. The refractor comes with the rings and a Losmandy-style base plate as well as a heavy-duty, reinforced nylon refractor case.

Since its founding in 1998, Stellarvue has refined its telescopes into some of the best instruments available today. Stellarvue's opticians quickly gained a reputation in the business as dedicated craftspeople, and the SVX 102T bears all the marks of their work, boasting an air-spaced triplet objective with high-quality glass and broadband coatings. Stellarvue claims it constructs each lens to a standard of 0.99 Strehl or higher, meaning 99 percent of incoming light is directed exactly where it's supposed to go. (A theoretical measurement of 1.00 is considered perfect.)

They even manufacture their own field flatteners, which reduce distortions and curvatures, ensuring pointlike stars throughout the entire field of view. Each

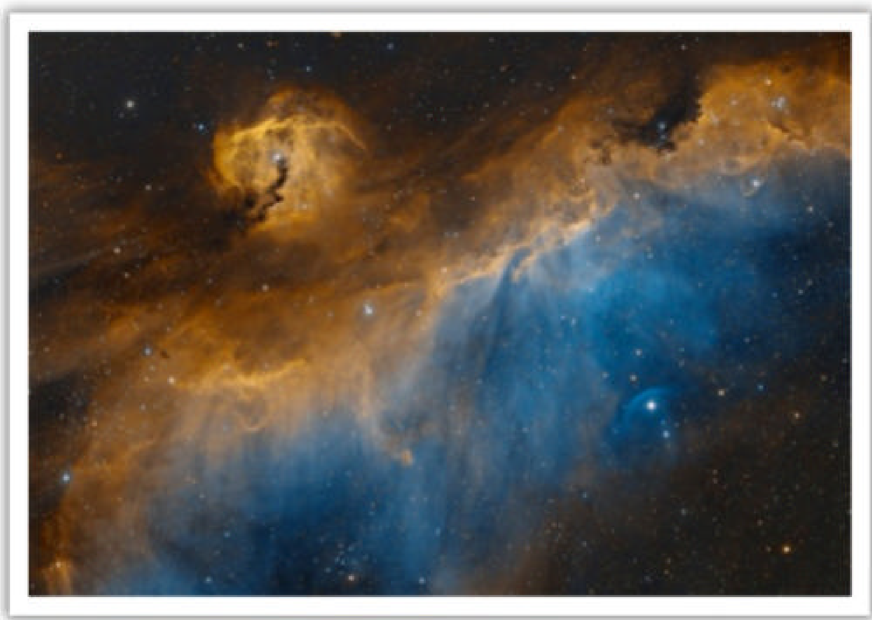
telescope Stellarvue manufactures comes with its own color interferometric test report taken at full aperture in the Stellarvue shop. This document confirms the accuracy of your individual objective.

All of these features taken together ensure a flat field, no false color, and pinpoint stars — all crucial for a demanding astrophotographer like myself. But having great optics means nothing if the telescope itself is not of the same quality. And while every SVX-designated telescope from Stellarvue has this level of performance, the 102T has some features that make it really shine.

First are numerous well-placed baffles inside the tube and along the focuser to help stop unwanted light from reaching the eyepiece. These and the rest of the interior are sprayed with a matte non-reflecting black paint, ensuring a telescope with extremely high contrast, both visually and photographically. This becomes important when trying to tease out faint details famous in some of the sky's best targets.

To further enhance this scope, Stellarvue also offers two field flatteners. For "straight through" flattening, there is the SFFX-1, which converts the scope to a 714mm f/7 astrograph/telephoto and allows you to capture perfect stars from corner to corner. Alternatively, for those wishing to compress the telescope to a shorter focal length and faster speed, there is the SFFR.74 reducer/flattener that gives a focal length of 535mm at f/5.25.

The Horsehead Nebula (center) is a dark nebula in the Orion constellation. To take this image, astrophotographer Alex Roberts used the SVX 102T scope with his QHYCCD 268C camera. ALEX ROBERTS



On the border between Monoceros and Canis Major constellations lies the Seagull Nebula (IC 2177). Using the SVX 102T scope, Roberts took this image with a ZWO ASI1600MM Pro camera. ALEX ROBERTS

PRODUCT INFORMATION

Stellarvue's SVX 102T
Aperture: 4 inches (101.5 mm)
Focal length: 714mm
Focal ratio: f/7
Length: 23.5 inches (59.7 centimeters) with focuser
Weight: 9.8 pounds (4.4 kilograms) with adapters
Price: \$2,995 with Stellarvue focuser; \$3,495 with Feather Touch focuser; \$5,399 with Moonlight Computerized NiteCrawler focuser
Contact: Stellarvue
11802 Kemper Road
Auburn, CA 95603, USA
530.823.7796

Putting it to the test

After using this scope for a few hours, you can easily see why views through a well-made refractor are addicting. The optics are virtually perfect. With this scope, stars are not just pinpoints — they are microscopic. Open clusters become brilliant jewels hung in a canopy of black. The crescent Moon is another treat as the color correction and the contrast are simply off the charts.

The flip side of a small refractor is that you need really high-power eyepieces to explore the other end of its performance. One good example is viewing the famous Double Double in Lyra, comprising two pairs of double stars. I love these stars for testing because the two pairs are aligned 90° to each other, making them nature's test for astigmatism. And the 102T proved itself astigmatism free. The stars split into perfect dots with identical inside and outside performance. A smaller scope already has an advantage in poor seeing conditions. And with the 102T, the stars jumped around instead of smearing out.

For me, the best performance test for any scope is your memory. After a night of viewing, can you still see in your mind what you looked at the previous night? With the 102T, my head was full of my previous night's observing.

While it doesn't show diffuse objects as well as a large Dobsonian, double stars, open clusters, the Moon, and the planets are a joy to behold in this scope. And, after seeing what the 102T can do, I'm eager to see how other scopes in Stellarvue's lineup perform. In fact, the highest praise I can give the 102T is that I've already ordered its bigger sibling, the SVX 140T — a 140mm refractor at f/6.7 — to add to my collection.

Tony Hallas *is one of the world's top astroimagers.*

Revisit the Giraffe

Make sure to explore all this constellation has to offer.

Like flowing rapids, the stars of Kemble's Cascade fall into NGC 1502 (bottom left). MICHAEL ISRAEL

BY PHIL HARRINGTON
Phil is a longtime contributor to Astronomy *and the author of many books.*

Back in the March issue, we visited the eastern portion of one of the sky's most challenging constellations, Camelopardalis the Giraffe. I promised then that we would return later in the year to call on some hidden deep-sky gems in the western part of the constellation. And here we are.

Like the eastern half, western Camelopardalis lacks any noteworthy naked-eye stars. So, finding our way around will take some effort. Fortunately, there is a neighbor who can help.

Cassiopeia borders Camelopardalis to the west. The full span of the Queen's familiar W pattern measures about 13° from tip to tip. Draw an imaginary line across the Cassiopeia W, from Caph (Beta [β] Cassiopeiae) to Segin (Epsilon [ε] Cassiopeiae), and extend it the same distance east into the emptiness of Camelopardalis. Look for a surprisingly straight stream of faint stars spanning 2.5° and flowing from northwest to southeast.

Canadian amateur astronomer and Franciscan monk Lucian Kemble first noticed this unusual grouping in 1980, while he was scanning Camelopardalis with 7x35 binoculars. Curious about this alignment, he contacted Walter Scott Houston to see if he was familiar with it. Houston — having written the Deep-Sky Wonders column in *Sky & Telescope* for more than four decades — was the preeminent deep-sky authority during the latter half of the 20th century. Despite this expertise, he was also previously unaware of Kemble's find. Houston alerted readers to this unusual sight, christening it **Kemble's Cascade.**

It's fun to scan the sky through binoculars to see what surprises await.

Fourteen stars make up Kemble's Cascade. Most are between 7th and 9th magnitude, save for a 5th-magnitude bluish sun midway along the stream. I liken it to a rock protruding out of a torrent of roaring rapids. But, despite appearances, the stars of Kemble's Cascade have no physical relation to each other in space. They are simply a chance line-of-sight alignment formed by unrelated stars, known as an asterism.

As you ride the rapids along Kemble's Cascade flowing southwestward, you will see that they end near a small, hazy patch. Kemble compared the view to a waterfall, with **NGC 1502** creating the cloud of water vapor at the base of the falls.

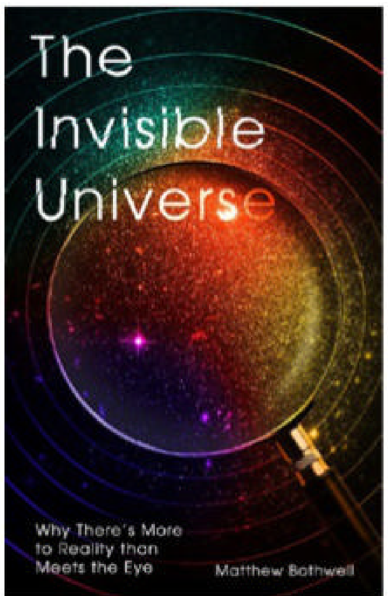
William Herschel discovered this open cluster in November 1787. NGC 1502 is made up of 45 stars, most of which are fainter than 10th magnitude — below the threshold for most binoculars. Despite their individual faintness, the stars combine their resources to create a 6th-magnitude object for us to enjoy. Look carefully and you might notice two or three faint points standing out from the cluster's glow. The brightest two shine at 7th magnitude and are dead center in the cluster. They form a tight pair separated by 16". That's too close to resolve through my 10x50 binoculars, but I can just detect their duality through my 16x70s. How many stars can you resolve in NGC 1502?

Our final stop on this visit to Camelopardalis is another object that went largely unknown until an amateur spotted it and began to spread the word. John Pazmino accidentally stumbled upon this open cluster while observing with a small refractor in the late 1970s. Although cataloged as **Stock 23**, many know it by its nickname: Pazmino's Cluster. To spot it, find the 4th-magnitude star HD 21291 about one binocular field southwest of NGC 1502. Stock 23 is just 1.6° farther west of this star. Viewing through my 10x50s, I can make out about a half-dozen of its 25 stars. The four brightest form a trapezoid reminiscent of Draco the Dragon's head.

Despite its late addition to the sky, Camelopardalis hosts quite a few hidden gems for amateurs to unearth. And it's fun to scan the sky through binoculars to see what surprises await, especially in barren spaces like Camelopardalis. You never know what you might come across.

Have you ever bumped into an interesting grouping of stars that no one else knows about? I'd love the spread the word. Drop me a line through my website, philharrington.net. Until next month, remember that two eyes are better than one.

BROWSE THE "BINOCULAR UNIVERSE" ARCHIVE AT **www.Astronomy.com/Harrington**



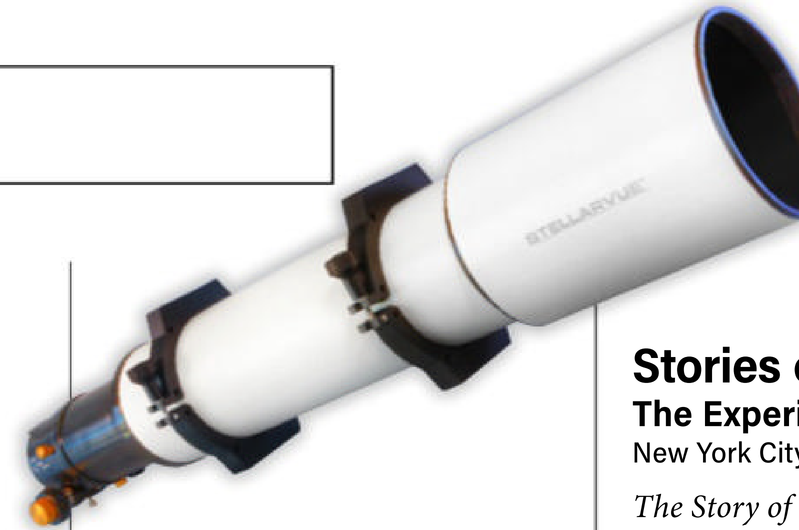
The hidden universe

Simon & Schuster
New York City, New York

The Invisible Universe: Why There's More to Reality Than Meets the Eye is dives into the 99 percent of the cosmos that astronomers can't see. The debut book of Matthew Bothwell of the University of Cambridge's Institute of Astronomy, *The Invisible Universe* is a 320-page cosmic detective story exploring how scientists have used the full spectrum of light to unravel the mysteries of the universe.

$27.95 (hardcover); $14.99 (ebook)
212.698.7000
www.simonandschuster.com

Attention, manufacturers: To submit a product for this page, email **products@astronomy.com**.



5-inch refractor

Stellarvue
Auburn, California

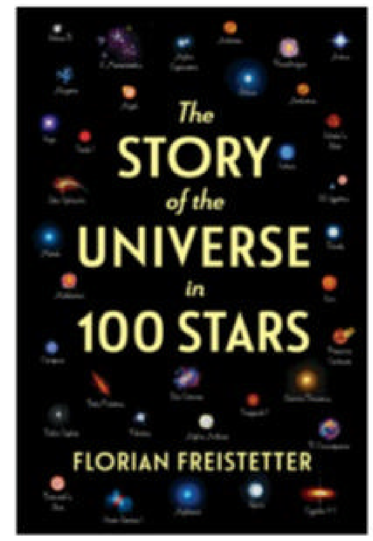
Stellarvue's SVX127D is a 127mm air-spaced APO doublet refractor with an f/8 focal ratio. The scope weighs 17 pounds (7.7 kilograms). It has a focal length of 1,016mm. A 3" dual-speed focuser, compression ring adapters, dovetail mounting base, and heavy-duty mounting rings are included.

$2,995.00 (introductory price, subject to change)
530.823.7796
www.stellarvue.com

Stories of stars

The Experiment
New York City, New York

The Story of the Universe in 100 Stars takes readers on a journey through the universe by exploring just a handful of its myriad stars. The 100 stars in the book were handpicked by author and astronomer Florian Freistetter, who explores each object's story as he weaves a narrative through the cosmos.

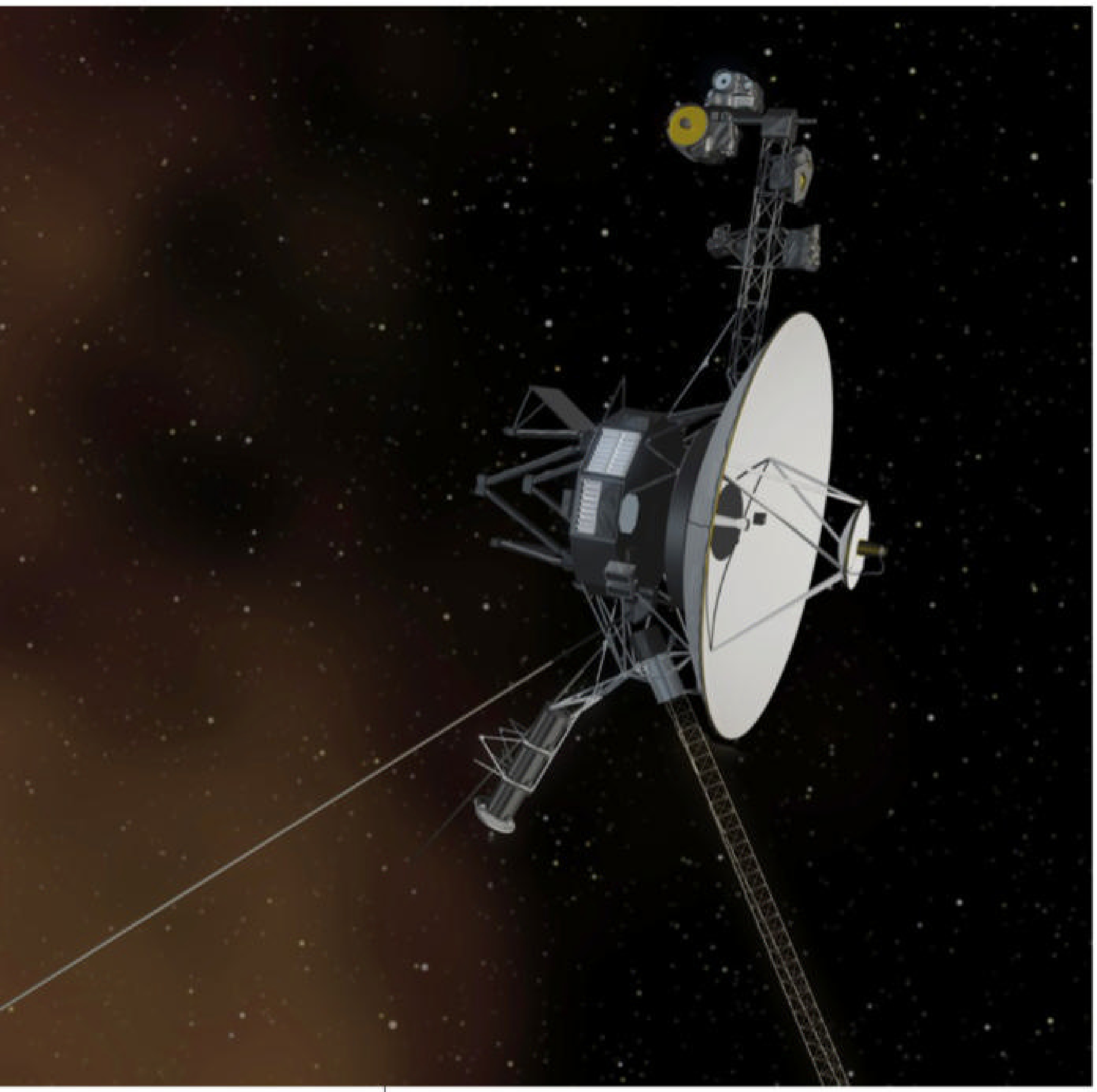


$21.95
212.889.1659
www.theexperimentpublishing.com

MARKETPLACE

INDEX *of* ADVERTISERS

The Advertiser Index is provided as a service to *Astronomy* magazine readers. The magazine is not responsible for omissions or for typographical errors in names or page numbers.



ABOVE: The twin Voyager spacecrafts launched in 1977 are the most distant human-made objects. To help propel them on their journey, the crafts took advantage of our solar system's largest planets. NASA/JPL-CALTECH

ABOVE RIGHT: A SpaceX Falcon 9 rocket lifts off from the Kennedy Space Center in Florida. NASA/KEVIN O'CONNELL & KENNY ALLEN

Rocket fuel

Q | WHAT KIND OF FUEL DO SPACECRAFT USE TO EXPLORE THE OUTER SOLAR SYSTEM AND BEYOND?

Larry Owen
Jamul, California

A | Sir Isaac Newton's first law of motion states that an object at rest stays at rest and an object in motion stays in motion with the same speed unless acted upon by an outside force. And in space, the only thing to slow down a spacecraft is gravity.

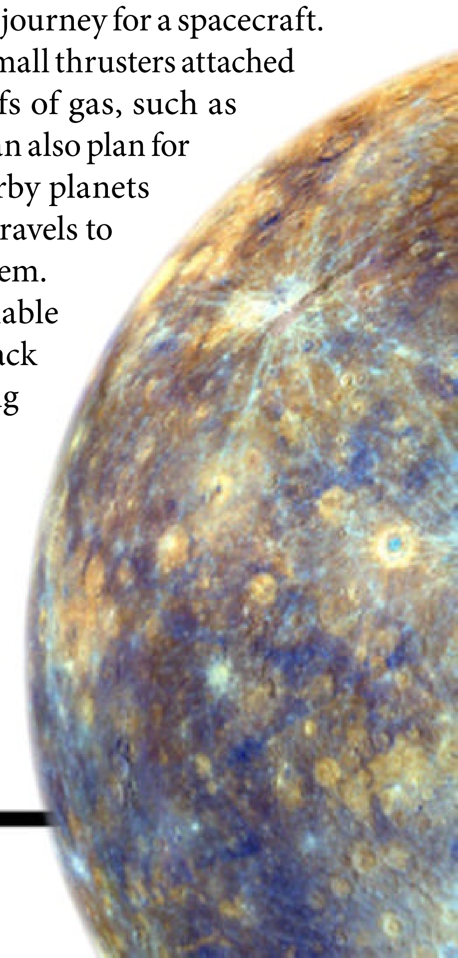
Before a spacecraft is even launched, scientists work out precisely where planets and other bodies will be to determine how the gravity of these objects will affect the trajectory of the craft. This allows them to calculate where to aim the craft, when to launch it, and how fast it needs to be traveling to reach its destination.

NASA then uses a two-pronged approach to fuel the launch. The rocket's main engines use a combination of liquid hydrogen and liquid oxygen. Hydrogen has the lowest molecular weight of any known substance, making it ideal for keeping the weight of a rocket relatively small. When combined with liquid oxygen, hydrogen creates the most efficient thrust of any rocket propellant.

But depending on the weight of the rocket, an extra boost may be needed to get off Earth. In these cases, solid propellent, usually aluminum, is combined with an explosive, such as ammonium perchlorate, to propel the rocket all the way into space.

But that's just the start of the journey for a spacecraft. For minor course corrections, small thrusters attached to the craft fire off small puffs of gas, such as hydrogen peroxide. Scientists can also plan for gravitational assists from nearby planets for an extra boost as the craft travels to the far reaches of our solar system.

Spacecrafts also need a reliable supply of electricity to report back their findings. Crafts operating



Mercury's Caloris Basin appears on the upper right of the planet in this false-color image assembled using images taken by NASA's MESSENGER mission. NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/CARNEGIE INSTITUTION OF WASHINGTON

close to the Sun can reliably use solar panels. But as a probe moves further out in the solar system, the Sun's rays become too weak. In that case, it can use radioisotope thermoelectric generators, which is a fancy way to say nuclear batteries. As radioactive material decays, it releases heat that can be converted into electricity for the craft.

Caitlyn Buongiorno
Associate Editor

Q | WHAT HAPPENED TO THE DEBRIS FROM THE COLLISION THAT FORMED THE CALORIS BASIN ON MERCURY? WHY DIDN'T IT FORM A MOON?

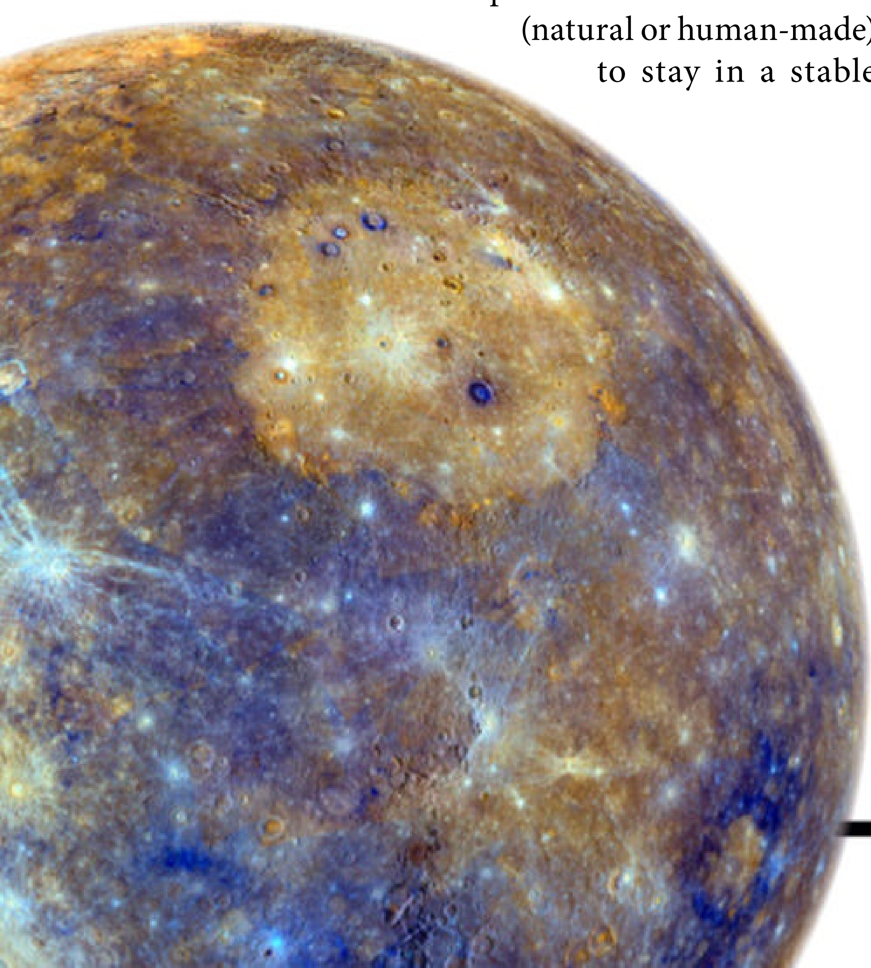
Fabian Marson
Wyndham Vale, Australia

A | Mercury's Caloris Basin is about 950 miles (1,525 kilometers) across. For comparison, the state of Texas is 773 miles (1,244 km) wide. The Moon has a similarly sized impact crater, Mare Orientale.

Researchers estimate that the collision that created the Caloris Basin occurred some 3.8 billion years ago, when a small body about 93 miles (150 km) across crashed into the planet. The impact sent seismic waves rumbling around the planet and even through its core. These tremors disrupted the surface on the opposite side of Mercury, jumbling it into what researchers call "weird" terrain.

As to why the impactor didn't create a debris disk that eventually coalesced into a moon like Earth's, the simple answer is that Mercury is too close to the Sun and its mass is too small. Every object has a region around it in which its gravity dominates, known as the Hill sphere. In order for a satellite (natural or human-made) to stay in a stable orbit around a body, that satellite needs to be within the Hill sphere. In our solar system, a planet's Hill sphere is dictated by its orbit (more specifically, its orbit's semi-major axis — the long semidiameter of an oval), its mass, and the Sun's mass. In Mercury's case, its Hill sphere is so small that any debris flung up from the impact that created the Caloris Basin either careened out of the Hill sphere and into the Sun, or crashed back into the planet, rather than lucking into a stable orbit and forming a moon.

Caitlyn Buongiorno
Associate Editor



Japanese amateur astronomer Akira Fujii captured this close-up shot of the sky's brightest star. The Sirius star system contains two stars, but so far no identified planets. AKIRA FUJII

Q | IS SIRIUS PART OF THE MILKY WAY? DOES IT HAVE ANY KNOWN PLANETS?

Thomas Steiner
Greendale, Wisconsin

A | Sirius is the brightest star in the Northern Hemisphere. In order to see a pointlike star with your naked eye, it must be relatively close to us; this means that all the stars you can see in the night sky are within the Milky Way Galaxy. Resolving individual stars in other nearby galaxies, such as Andromeda in the Northern Hemisphere or the Large and Small Magellanic Clouds in the Southern Hemisphere, requires professional equipment like the Hubble Space Telescope.

Sirius is about 8.6 light-years from Earth. There are two identified stars in the Sirius star system, a main sequence spectral type A star and a faint white dwarf, designated Sirius A and B, respectively. No planets have been identified in the system so far. Combining Hubble observations with historical measurements dating back to the 19th century, researchers have ruled out the possibility of any brown dwarfs or any exoplanets larger than 15 times the mass of Jupiter. However, looking at our own solar system's plethora of smaller planets, it's not a stretch to imagine that there could be a considerable number of exoplanets evading detection in this system.

Caitlyn Buongiorno
Associate Editor

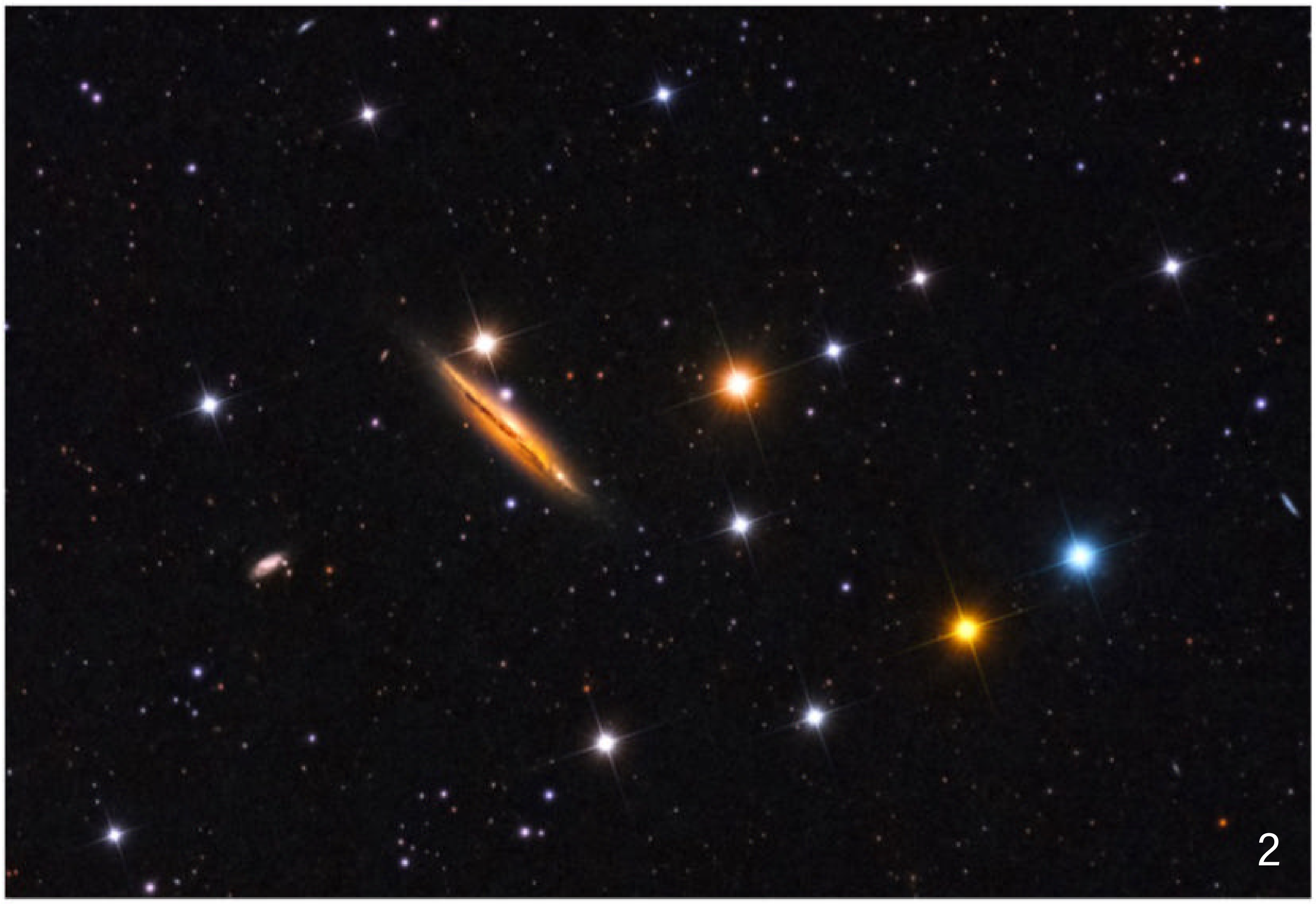
SEND US YOUR QUESTIONS

Send your astronomy questions via email to askastro@astronomy.com, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

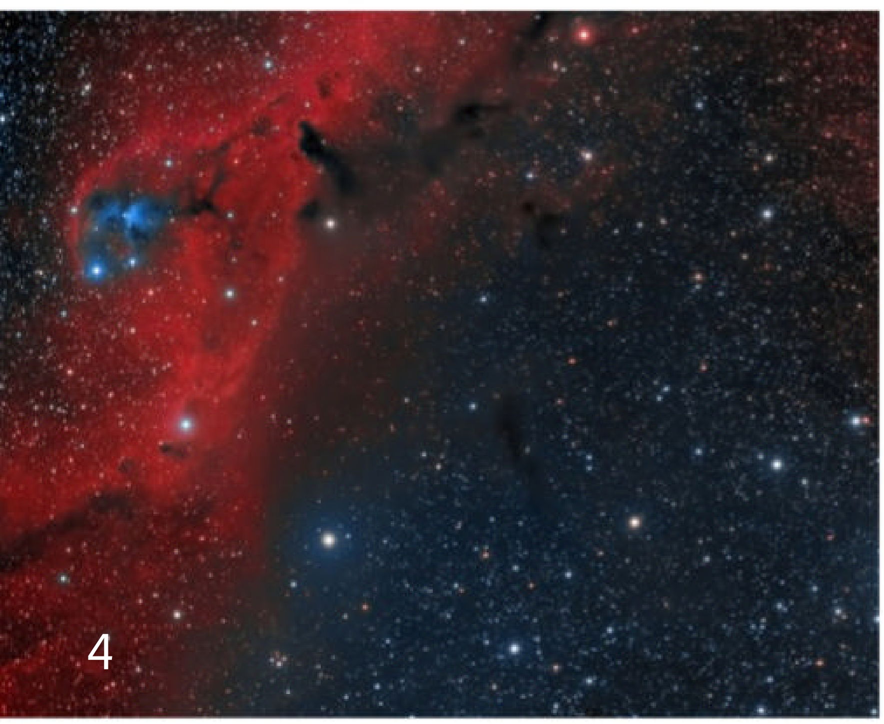
Cosmic portraits

1. GATEWAY TO THE GALAXY
The natural limestone arch of Durdle Door on England's Jurassic Coast lies at the end of the Milky Way in this composite image. The photographer used two cameras to capture this scene: 15 one-minute exposures with a 24mm lens at f/2.8 and ISO 1600 on a tracking mount to image the sky, and 15 fifteen-second exposures with a 14mm lens at f/2.8 and ISO 3200 for the foreground. ▪ ***Emil Andronic***

2. APPARENT NEIGHBORS
The edge-on spiral NGC 4217 glows from 60 million light-years away, appearing next to a colorful array of foreground stars in Canes Venatici. NGC 4217 may be a gravitational companion to M106, which lies roughly ½° east-northeast (outside the frame). The image was made with one hour, 45 minutes of exposure and a 5-inch scope. ▪ ***Kasra Karimi***




3


4


5


6

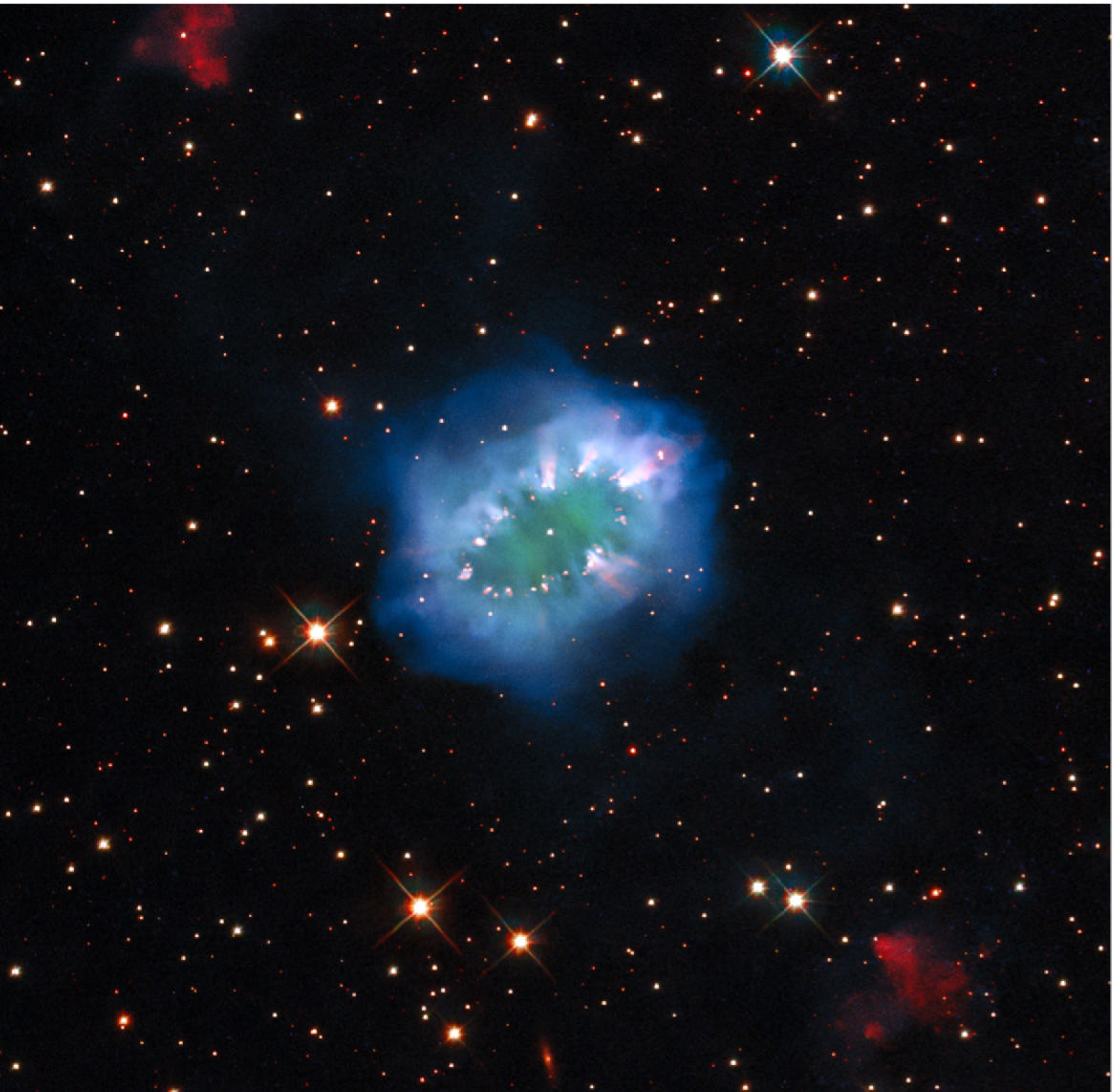
3. GANDALF THE GREEN
The Wizard Nebula is a cloud of gas and dust that surrounds the young open cluster NGC 7380, some 10,000 light-years away in Cepheus. The soft viridescent hues are thanks to a creative HαSOO combination of filter data, with Hα used for the luminance channel, SII mapped to red, and OIII mapped to both green and blue. The image represents 13 hours of total exposure with an 8-inch scope.
• *Chad Leader*

4. RED VS. BLUE
The dark clouds Barnard 30/31/32 in Orion cast their shadows across the red glow of an emission nebula at upper left, just next to the blue reflection nebula at upper left. Another diffuse reflection nebula occupies the lower right. This LRGB image was made with a 4.2-inch scope over nearly 10.5 hours of observations.
• *César Blanco González*

5. FLY ME TO THE MOON
As the photographer was taking shots of the 92.1-percent illuminated Moon in Kolkata, India, on July 21, 2021, an airliner happened to photobomb the camera's view and transit the Moon's disk.
• *Soumyadeep Mukherjee*

6. PERSEID PLETHORA
Seventeen Perseid meteors streak across the skies over Cedar Rapids, Iowa, in this composite image from Aug. 14, 2021. Each meteor streak is a separate 20-second exposure at a focal length of 16mm, f/2.8, and ISO 400. **• *Gregg Alliss***

SEND YOUR IMAGES TO:
Astronomy Reader Gallery, P.O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to **readergallery@astronomy.com.**



TWO STARS FORGE A DIAMOND NECKLACE

The aptly named Necklace Nebula dazzles from 15,000 light-years away. This planetary nebula started developing some 10,000 years ago from two closely orbiting stars. As the more massive component neared the end of its life, it expanded and quickly enveloped its companion. The smaller sun didn't flinch, however, and began to transfer its orbital angular momentum to the swollen star's rotation. When the giant's gravity could no longer hold on to its fast-moving outer layers, they spun off. The densest clumps of ejected debris created the necklace's sparkling "diamonds." Just a few million miles now separate the dying star's core from the companion sun — too close for even the Hubble Space Telescope to split them. ESA/HUBBLE & NASA/K. NOLL

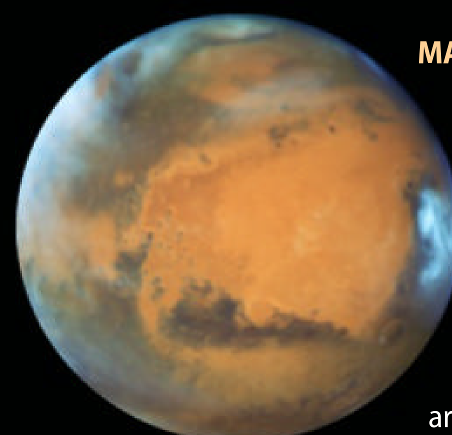
Astronomy's 2022 Guide to the Night Sky

LUNAR PHASES

New	First Quarter	Full	Last Quarter
Jan. 2	Jan. 9	Jan. 17	Jan. 25
Feb. 1	Feb. 8	Feb. 16	Feb. 23
March 2	March 10	March 18	March 25
April 1	April 9	April 16	April 23
April 30	May 8	May 16	May 22
May 30	June 7	June 14	June 20
June 28	July 6	July 13	July 20
July 28	Aug. 5	Aug. 11	Aug. 19
Aug. 27	Sept. 3	Sept. 10	Sept. 17
Sept. 25	Oct. 2	Oct. 9	Oct. 17
Oct. 25	Nov. 1	Nov. 8	Nov. 16
Nov. 23	Nov. 30	Dec. 7	Dec. 16
Dec. 23	Dec. 29		

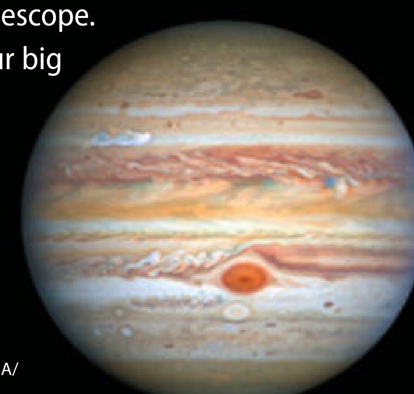
All dates are for the Eastern time zone. A Full Moon rises at sunset and remains visible all night; a New Moon crosses the sky with the Sun and can't be seen.

VENUS shines at dusk on the first few evenings of 2022. After vanishing in the Sun's glare, it returns to view before sunrise in mid-January. The inner planet then remains a morning object until September. Venus reaches greatest elongation from the Sun in March, when it stands some 10° high in the southeast an hour before sunrise and gleams at magnitude –4.5. NASA/JPL-CALTECH



MARS appears obvious before dawn in early 2022, but it grows more prominent each month as it brightens and climbs higher. The Red Planet reaches opposition in early December, when it shines at magnitude –1.9 and shows a disk 17" across when viewed through a telescope. It then lies high around midnight among the background stars of Taurus. NASA/ESA/STSCI

JUPITER always looks dramatic through a telescope. Even small instruments show the planet's four big moons and resolve its dynamic atmosphere into an alternating series of bright zones and darker belts. Jupiter appears best around opposition in late September, when it shines brightest (magnitude –2.9) and looms largest (50" across), though it's a fine sight from April through the end of the year. NASA/ESA/ A. SIMON (GSFC)/M. H. WONG (UC, BERKELEY)/THE OPAL TEAM



SATURN provides a stunning attraction for telescope owners from March through year's end. The ringed planet reaches its peak in mid-August. It then shines at magnitude 0.2 and its disk measures 19" across, while the rings span 43" and tilt 14° to our line of sight. NASA/ ESA/THE HUBBLE HERITAGE TEAM (STSCI/AURA)

THE MOON is Earth's nearest neighbor and the only celestial object humans have visited. Because of its changing position relative to the Sun and Earth, the Moon appears to go through phases, from a slender crescent to Full Moon and back. The best times to observe our satellite through a telescope come a few days on either side of its two Quarter phases. For the best detail, look along the terminator — the line separating the sunlit and dark parts. NASA/GSFC/ARIZONA STATE UNIVERSITY

WINTER

The sky

Winter boasts the brightest stars of any season. Orion the Hunter dominates the evening sky this time of year. Its seven most prominent stars form a distinctive hourglass pattern. The blue star marking Orion's left foot is Rigel, and the ruddy gem at his right shoulder is Betelgeuse. The three stars of the Hunter's Belt point down to Sirius, the brightest star in the night sky, and up to Aldebaran, the eye of Taurus the Bull. To Orion's upper left lies the constellation Gemini.

Deep-sky highlights

The Pleiades (M45) is the brightest star cluster in the sky. It looks like a small dipper, but it is not the Little Dipper.
The Orion Nebula (M42), a region of active star formation, is a showpiece through telescopes of all sizes.
The Rosette Nebula (NGC 2237–9/46), located 10° east of Betelgeuse, presents an impressive cluster of stars and a nebula.
M35 in Gemini the Twins is a beautiful open cluster best viewed with a telescope.
Castor (Alpha [α] Geminorum) is easy to split into two components with a small telescope, but the system actually consists of six stars.

Jan. 3
Quadrantid meteor shower peaks

Jan. 7
Mercury is at greatest eastern elongation

March 20
Venus is at greatest western elongation

April 29
Mercury is at greatest eastern elongation

April 30
Venus passes 0.2° south of Jupiter

May 6
Eta Aquariid meteor shower peaks

May 15/16
Total lunar eclipse

July 19
Pluto is at opposition

Aug. 12
Perseid meteor shower peaks

Aug. 14
Saturn is at opposition

Aug. 22
Asteroid Vesta is at opposition

SPRING

The sky

The Big Dipper, the most conspicuous part of the constellation Ursa Major the Great Bear, now rides high in the sky. Poke a hole in the bottom of the dipper's bowl, and the water would fall on the back of Leo the Lion. The two stars at the end of the bowl, called the Pointer Stars, lead you directly to Polaris, the North Star: From the bowl's top, simply go five times the distance between the Pointers. Spring is the best time of year to observe a multitude of galaxies. Many of these far-flung island universes, containing hundreds of billions of stars, congregate in northern Virgo and Coma Berenices.

Deep-sky highlights

The Beehive Cluster (M44) was used to forecast weather in antiquity. It is a naked-eye object under a clear, dark sky, but it disappears under less optimal conditions.
M5, a conspicuous globular cluster, lies between the figures of Virgo the Maiden and Serpens Caput the Serpent's Head.
The Whirlpool Galaxy (M51) is a vast spiral about 30 million light-years away.
M81 and **M82** in Ursa Major form a pair of galaxies that you can spot through a telescope at low power.

STAR MAPS BY *ASTRONOMY*: ROEN KELLY

Sept. 16
Neptune is at opposition

Sept. 26
Jupiter is at opposition

Oct. 8
Mercury is at greatest western elongation

Oct. 21
Orionid meteor shower peaks

Oct. 25
Partial solar eclipse

Nov. 8
Total lunar eclipse

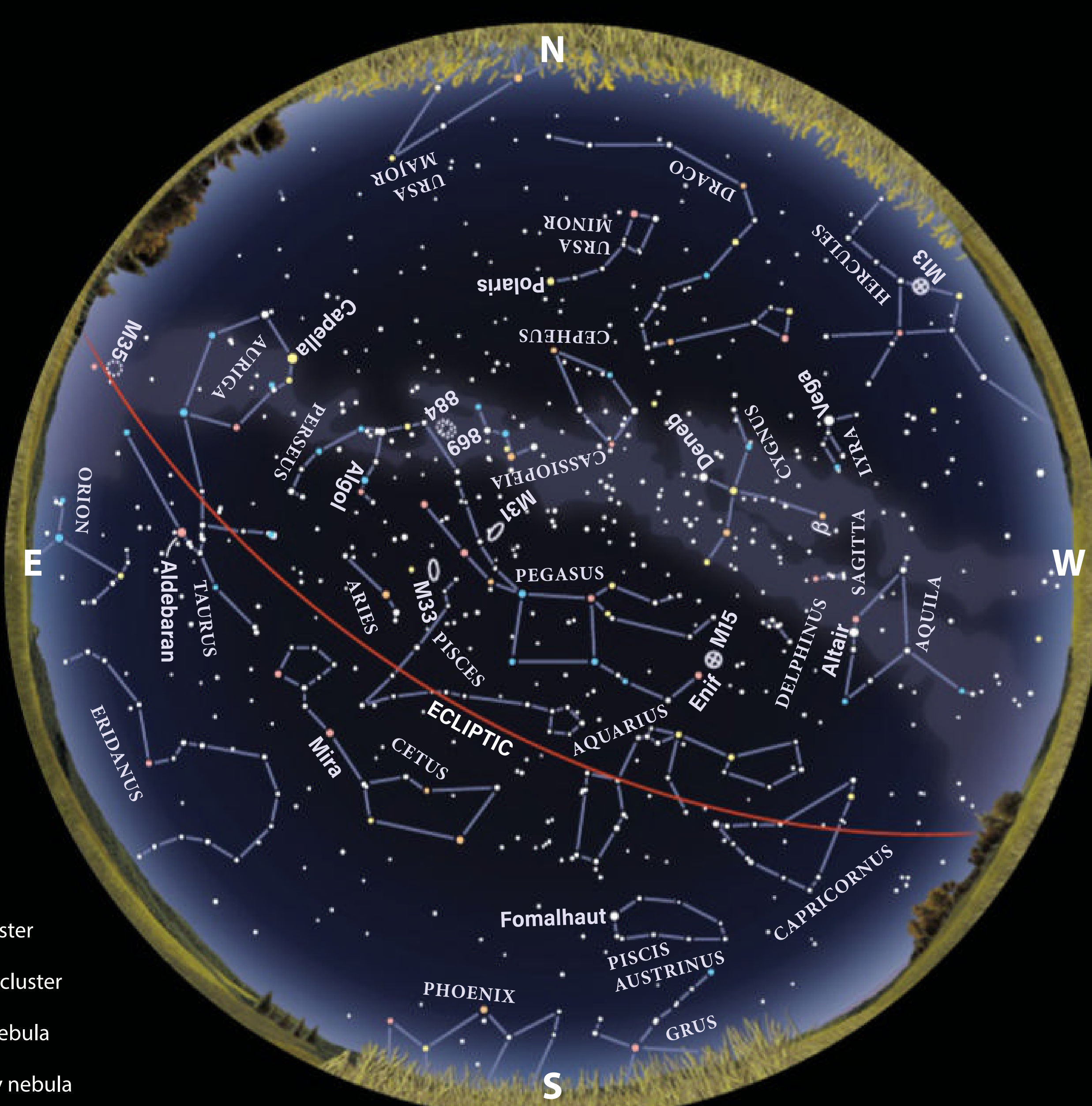
Nov. 9
Uranus is at opposition

Nov. 17
Leonid meteor shower peaks

Dec. 8
Mars is at opposition

Dec. 14
Geminid meteor shower peaks

Dec. 21
Mercury is at greatest eastern elongation



Open cluster
Globular cluster
Diffuse nebula
Planetary nebula
Galaxy

SUMMER

The sky

High in the sky, the three bright stars known as the Summer Triangle are easy to spot. These luminaries — Vega in Lyra, Deneb in Cygnus, and Altair in Aquila — lie near the starry path of the Milky Way. Following the Milky Way south from Aquila, you'll find the center of our galaxy in the constellation Sagittarius the Archer. Here lie countless star clusters and glowing gas clouds. Just west of Sagittarius is Scorpius the Scorpion, which contains the red supergiant star Antares as well as M6 and M7, two brilliant clusters that look marvelous at low power.

Deep-sky highlights

The Hercules Cluster (M13) contains nearly a million stars and is the finest globular cluster in the northern sky.

The Ring Nebula (M57) looks like a puff of smoke through a medium-sized telescope.

The Omega Nebula (M17) looks like the Greek letter of its name (Ω) through a telescope at low power. This object also is called the Swan Nebula.

The Wild Duck Cluster (M11) is a glorious open star cluster. On a moonless night, a small scope will show you some 50 stars.

AUTUMN

The sky

The Big Dipper swings low this season, and from parts of the southern United States, it even sets. With the coming of cooler nights, Pegasus the Winged Horse rides high in the sky as the rich summer Milky Way descends in the west. Fomalhaut, a solitary bright star, lies low in the south. The magnificent Andromeda Galaxy reaches its peak nearly overhead on autumn evenings, as does the famous Double Cluster. Both of these objects appear as fuzzy patches to the naked eye under a dark sky.

Deep-sky highlights

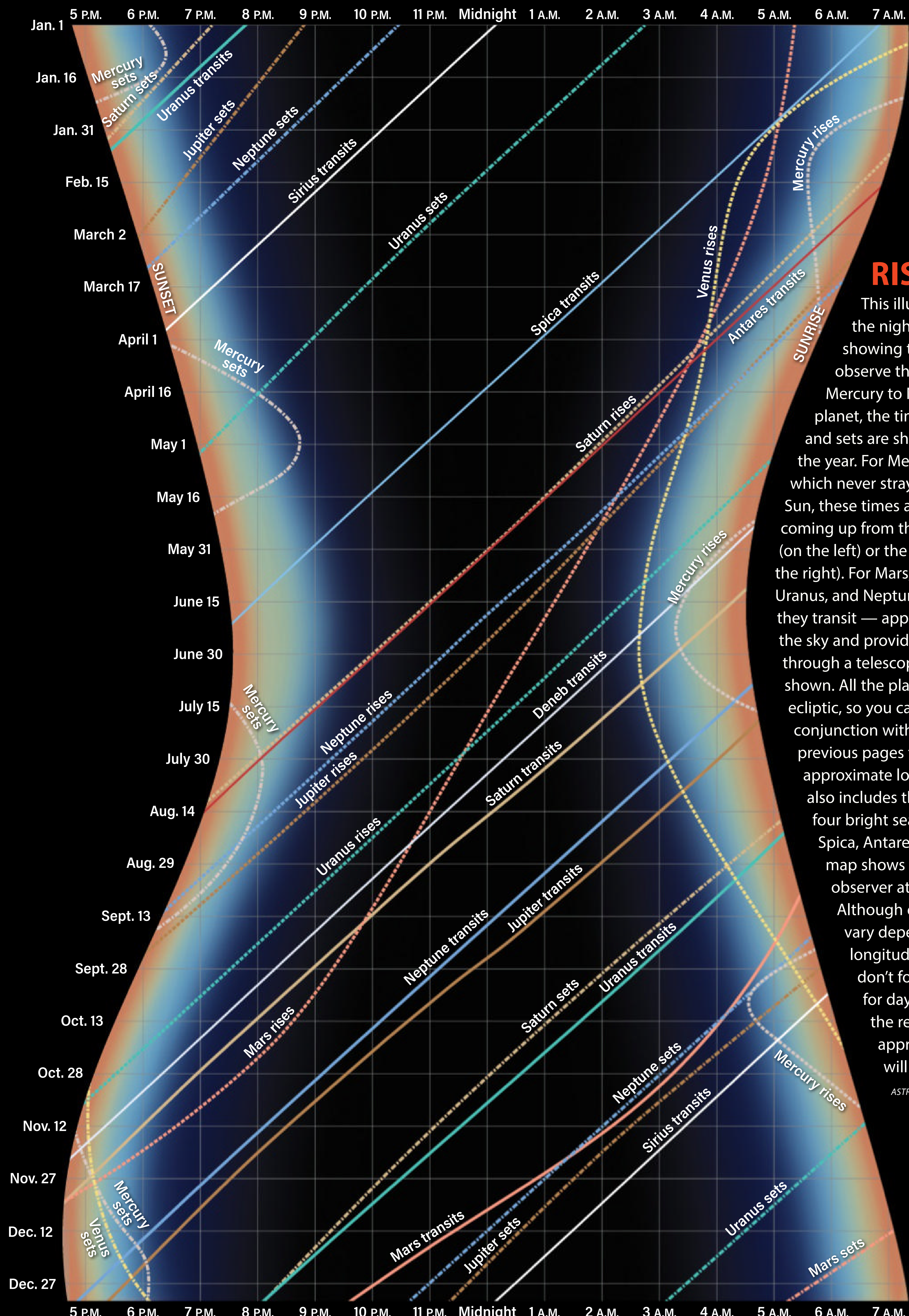
The Andromeda Galaxy (M31) is the brightest naked-eye object outside our galaxy visible in the northern sky.

The Double Cluster (NGC 869 and NGC 884) in Perseus consists of twin open star clusters. It's a great sight through binoculars.

M15 in Pegasus is a globular cluster containing hundreds of thousands of stars, many of which can be glimpsed through a medium-sized telescope.

Albireo (Beta [β] Cygni), the most beautiful double star in the sky, is made up of suns colored sapphire and gold.

Astronomy magazine



RISE & SET

This illustration presents the night sky for 2022, showing the best times to observe the planets from Mercury to Neptune. For each planet, the times when it rises and sets are shown throughout the year. For Mercury and Venus, which never stray too far from the Sun, these times appear as loops coming up from the sunset horizon (on the left) or the sunrise horizon (on the right). For Mars, Jupiter, Saturn, Uranus, and Neptune, the times when they transit — appear highest in the sky and provide the best view through a telescope — also are shown. All the planets lie near the ecliptic, so you can use this chart in conjunction with the maps on the previous pages to find a planet's approximate location. The chart also includes the transit times of four bright seasonal stars: Sirius, Spica, Antares, and Deneb. This map shows local times for an observer at 40° north latitude. Although exact times will vary depending on your longitude and latitude (and don't forget to add an hour for daylight saving time), the relative times and approximate positions will stay the same.

ASTRONOMY: ROEN KELLY

February 2022

A parade of predawn planets

Early February offers a final chance to glimpse **Jupiter** in evening twilight. On the 1st, the giant world stands only 7° high in the west 45 minutes after sunset. The planet shines brightly at magnitude –2.1, however, so it shows up easily if you have an unobstructed horizon. Jupiter disappears in the Sun's glow by mid-February and will be lost from view until it returns on mornings in late March.

Once Jupiter sets, skygazers have a long wait before the next bright planet emerges. The action picks up starting around 3 A.M. local time (4 A.M. daylight time), when **Mars** pokes above the eastern horizon. The Red Planet remains rather dim this month, brightening slightly from magnitude 1.4 to 1.3 against the backdrop of Sagittarius the Archer. Despite this constellation's fame, its luminary — magnitude 1.8 Epsilon (ε) Sagittarii — appears noticeably fainter than Mars. A telescope shows the planet as a featureless disk spanning 5".

Not long after Mars clears the horizon, **Venus** joins the scene. Although the inner planet always shines brightly, it appears especially stunning this month. Venus peaks at magnitude –4.9 when it hits greatest brilliancy February 12. That makes it not only 300 times brighter than Mars but also 25 times brighter than Sirius, the night sky's most dazzling star.

Telescopic observers will be rewarded with spectacular views of Venus all month. At the beginning of February, Earth's neighbor spans 49" and appears just 15 percent lit. The disk is large enough that good binoculars can reveal the planet's delightful crescent. As Venus moves away from us during the month, its apparent size shrinks as its phase waxes. But even by February 28, its disk measures 32" across and appears 37 percent illuminated. Although Venus appears well clear of the horizon by the time dawn starts to break, many observers find it a more tempting subject during twilight because the background light cuts the planet's glare.

The morning sky grows more crowded about an hour after Venus rises. February finds **Mercury** putting on its finest predawn show of 2022. The innermost planet begins the month 17° west of the Sun and rising some 70 minutes before sunup. Glowing at magnitude 1.1, Mercury stands out low in the east-southeast as twilight starts to brighten.

The inner world grows more prominent as it climbs higher and grows brighter during the next two weeks. At greatest western elongation February 16, the magnitude 0.1 planet rises two hours before the Sun and appears 12° high an hour later. Although Mercury sinks closer to the Sun as February winds down, it remains conspicuous through month's end.

As you might expect, February mornings also provide an excellent opportunity to observe Mercury through a telescope. The best views come early in the month when the planet shows a large crescent. On the 1st, its disk spans 9.4" and appears 20 percent lit. On the morning of its greatest elongation, Mercury measures 6.9" across and the Sun illuminates 60 percent of its Earth-facing hemisphere.

As if these three terrestrial planets weren't enough, a gas giant world adds to the spectacle. Although **Saturn** passes behind the Sun from our viewpoint February 4, it reappears in morning twilight during the month's final 10 days. To find it on the 18th, simply draw a line from Mars to Mercury and extend it an equal distance toward the horizon. By the 28th, Saturn stands 4° directly below Mercury. The gas giant shines at magnitude 0.7 and appears half as bright as its neighbor. Unfortunately, the ringed planet won't look like much through a telescope until it climbs higher next month.

Be sure to watch the waning crescent Moon slide past these planets on the final two mornings of February (and the first of March). To capture a great photo, shoot during twilight with a striking terrestrial scene in the foreground.

The starry sky

Northern Hemisphere observers wax poetic about the Summer Triangle: the bright stars Altair, Deneb, and Vega that appear so prominent on northern summer evenings. For us in the Southern Hemisphere, of course, that triangle lies in the winter sky and isn't impressive because only Altair climbs high.

So let's focus instead on the Southern Hemisphere's Summer Triangle. February evenings are the perfect time to appreciate the geometric shape formed by Betelgeuse, Procyon, and Sirius, all three of which rank among the night sky's 10 brightest stars.

I find our Summer Triangle more aesthetically pleasing because it creates a nearly perfect equilateral triangle. The angular distance from ruddy Betelgeuse to Procyon is 26.0°, from Procyon to brilliant Sirius is 25.7°, and from Sirius back to Betelgeuse is 27.1°. Compare that with the Northern Hemisphere's far less symmetric Summer Triangle: The longest side of the triangle runs from Deneb to Altair and spans 38.0°, Altair to Vega spans 34.2°, and Vega back to Deneb covers just 23.8°.

Of course, any three celestial objects can form a triangle. One of my favorites appears late on February evenings and provides a convenient way to locate the sky's brightest globular cluster, Omega (ω) Centauri (NGC 5139), with just your naked eye. Omega forms the northern vertex of a nearly equilateral triangle with the bright stars Beta (β) Cen and Gamma (γ) Crucis. The triangle's three sides measure 12.4°, 12.8°, and 14.0°.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. February 1
9 P.M. February 15
8 P.M. February 28

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

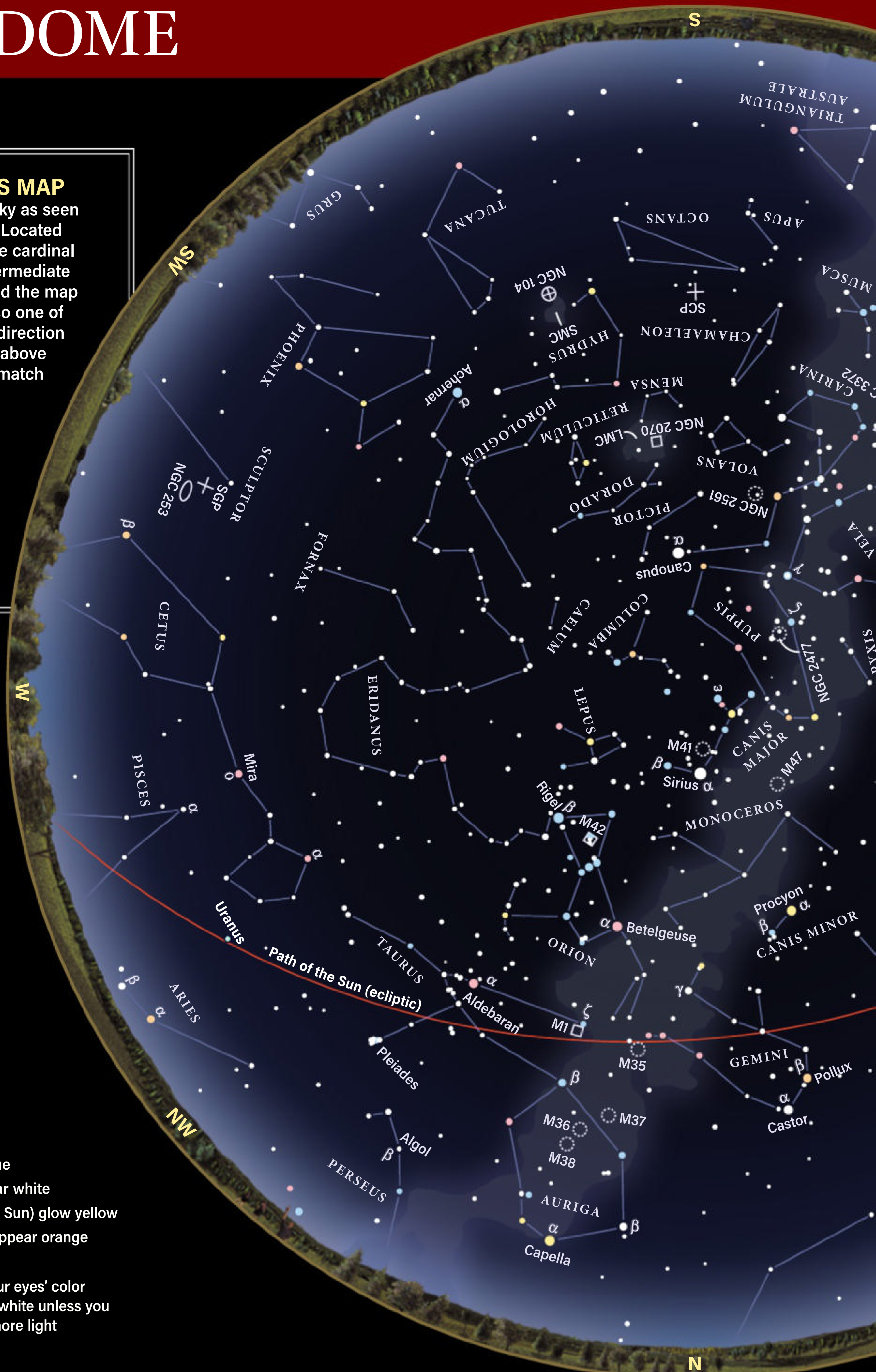
STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light



BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

FEBRUARY 2022

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28					

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 New Moon occurs at 5h46m UT

2 The Moon passes 4° south of Jupiter, 21h UT

3 The Moon passes 4° south of Neptune, 21h UT

Mercury is stationary, 22h UT

4 Saturn is in conjunction with the Sun, 19h UT

5 Asteroid Massalia is at opposition, 8h UT

7 The Moon passes 1.2° south of Uranus, 20h UT

8 First Quarter Moon occurs at 13h50m UT

9 The Moon passes 0.03° north of dwarf planet Ceres, 11h UT

11 The Moon is at apogee (404,897 kilometers from Earth), 2h37m UT

12 Venus is at greatest brilliancy (magnitude –4.9), 18h UT

13 Venus passes 7° north of Mars, 1h UT

16 Full Moon occurs at 16h56m UT

Mercury is at greatest western elongation (26°), 21h UT

23 Last Quarter Moon occurs at 22h32m UT

26 The Moon is at perigee (367,789 kilometers from Earth), 22h25m UT

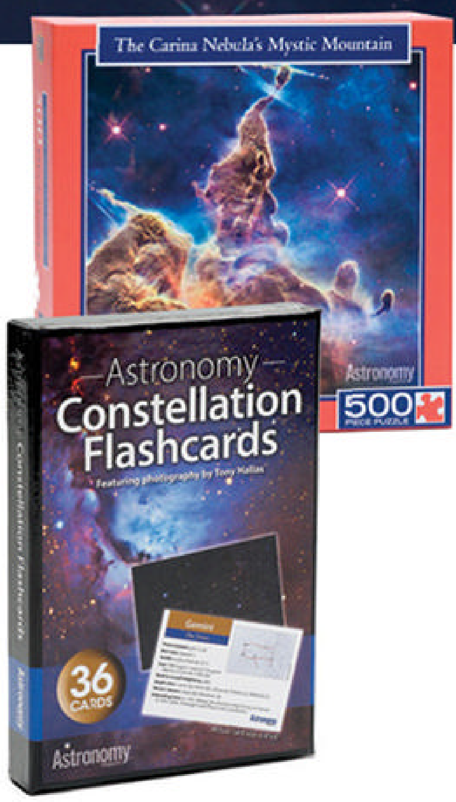
27 The Moon passes 9° south of Venus, 6h UT

The Moon passes 4° south of Mars, 9h UT

28 The Moon passes 4° south of Mercury, 20h UT

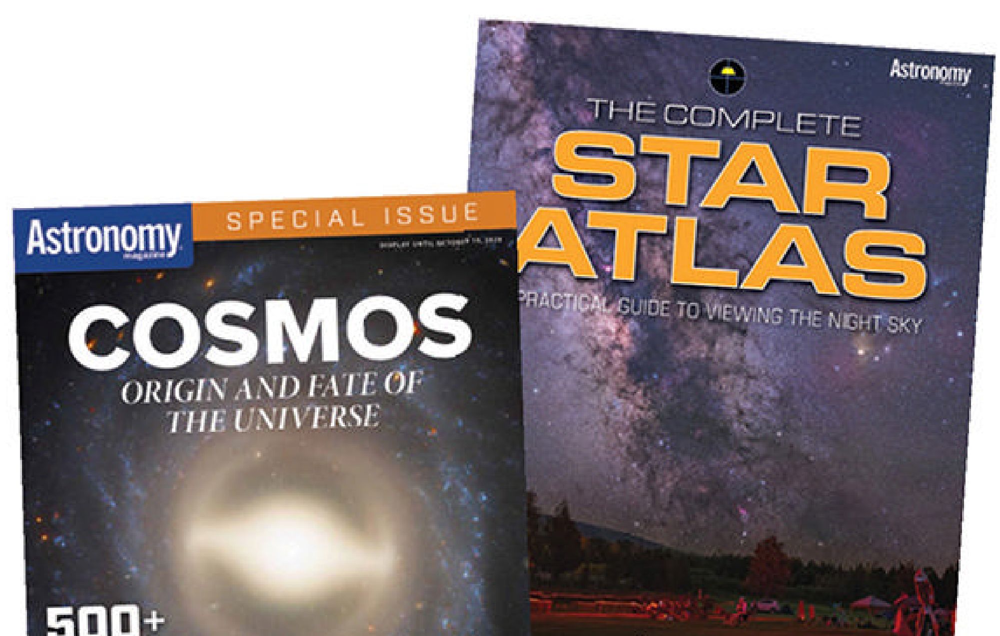
OVER
1000 PRODUCTS!
INCLUDING EXCLUSIVES
FROM *ASTRONOMY*

EXPLORE THE UNIVERSE



Visit MyScienceShop.com today for high-quality products curated by the *Astronomy* magazine team, including:

- Custom-produced globes, as well as others from top manufacturers.
- Books and DVDs covering solar eclipses, observing guides, the cosmos and more.
- Magazines bringing you the latest astronomical discoveries and events.
- Astronomy posters including many sold exclusively on MyScienceShop.com.
- Toys and games–have fun learning about astronomy!
- And much more!



MY SCIENCE SHOP

Shop now at:
MyScienceShop.com

Sales tax where applicable.

P39082